The State and Quality of Scientific Research in Finland

A Rewiew of Scientific Research and Its Environment in the Late 1990s

Edited by Kai Husso, Sakari Karjalainen & Tuomas Parkkari

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Introduction

The Academy of Finland gives a review of the state and quality of scientific research in the country once during the three-year term of its Research Councils. The previous report was published in 1997. The Academy's responsibilities with respect to evaluation are spelled out in the Government's decisions on the development of education and research (the current five-year development plan covers the period from 1999 to 2004) and in the Agreement on Target Outcomes between the Ministry of Education and the Academy of Finland. The Academy is also charged with the responsibility to conduct assessments of individual disciplines and research programmes and to develop indicators for evaluation purposes.

The main target groups of this review are the organisations and the people who are involved in formulating science and technology policy objectives and in making decisions on the funding and development of the science system. For them, the review provides an opportunity to weigh the impacts of research and the science system from a social, economic and cultural point of view. It is also intended for researchers, heads of research organisations and scientific societies concerned with the roles and objectives of scientific research in a world of accelerating change.

The total R&D expenditure has increased substantially in Finland since the previous review in 1997: this can be attributed to the Government's additional funding programme (1997–1999) as well as a marked increase in funding from and R&D conducted by the private sector. The main purpose of this review is to look at the development of the Finnish science system in the late 1990s and at expectations of how the changes will impact research and development. More specifically, the aims of the review are to:

- describe the current environment of science policy and research in Finland and the trends leading up to the current situation;
- analyse the impacts of changes in the environment from the point of view of universities and basic research in particular;
- examine the qualitative and quantitative development of Finnish research in recent years;
- identify and analyse the strengths and weaknesses of Finnish research and the Finnish science system;
- examine the mechanisms through which research exerts its impact in society and on the development of society.

The report is divided into *five chapters* that support one another but that also read as independent pieces. *Chapter One* discusses the recent development of science and technology policy from a global perspective and analyses the role of scientific research in the national innovation system. *Chapter Two* describes the main objectives of Finnish science policy in the latter half of the 1990s and the ways in which those objectives have been pursued. *Chapter Three* looks at the changes that have happened in the research environment from the viewpoint of universities and describes their strategies of adaptation and change. Chapters two and three deal partly with the same issue from opposite angles, i.e. from the viewpoint of funding bodies on the one hand and that of research organisations, on the other. *Chapter Four* discusses questions of research output as well as the assessment of research impacts, and, by exploiting bibliometric data and methods, investigates how Finnish research compares internationally and how its output and quality has developed during the 1990s. The chapter also provides general assessments of the impacts of Finnish research. Finally, *Chapter Five* summarises the main findings and conclusions of all four chapters, providing a foundation for a discussion of how to go about the challenge of further developing Finnish research and the Finnish science system.

The series of six reports that was published in 1997 on the state and quality of scientific research in Finland was chiefly concerned with exploring the situation in individual disciplines. This report looks at scientific research from the vantage-point of the science system as a whole. As well as shifting the focus from individual disciplines to the science system as a whole, this review differs from the 1997 evaluation in the sense that it involves more international comparison. For instance, research funding in Finland, the structure of the science system and research output are compared with the situation in other OCED countries.

The review was prepared under the supervision of a steering group appointed by the Board of the Academy of Finland. Chaired by the Academy's Director of Research Jorma Hattula, the other group members were as follows: Professor Markku Mattila (Chair of the Research Council for Natural Sciences and Engineering), Professor Aili Nenola (Chair of the Research Council for Culture and Society), Professor Terttu Vartiainen (Chair of the Research Council for the Environment and Natural Resources), Professor Eero Vuorio (Chair of the Research Council for Health), Secretary General Kauko Hämäläinen from the Finnish Higher Education Evaluation Council, Director Matti Lähdeoja (Science Policy Unit; during the initial stages), Director Arvo Jäppinen (during the latter stages) and Senior Adviser Marja Pulkkinen (standing in for the former two) from the Ministry of Education, and Project Manager Paavo Löppönen from the Academy of Finland. The steering group worked collectively to plan the report and to process draft versions. In addition, group members were consulted individually during the preparation of separate chapters.

The material for the review was prepared and the actual text written by a project group chaired initially by Head of Development Jaakko Rusama and from the beginning of 1999 by Sakari Karjalainen, Secretary General of the Academy's Research Council for Health. The following project group members were involved in preparing and writing this report: Project Secretary Tuuli Ahava (Chapter 3); Scientific Secretary Anneli Ahvenniemi (Chapter 2); Senior Researcher Kai Husso (Chapters 1, 4 and 5, and Appendix 1); Senior Researcher Timo Kolu (Chapter 2); Senior Researcher Hannele Kurki (Chapter 3); Scientific Secretary Annamaija Lehvo (Chapter 2); Scientific Secretary Tero Majamaa; Information Specialist Maija Miettinen (Chapter 4 and Appendix 1); Scientific Secretary Tuomas Parkkari (Chapters 2 and 4); Project Secretary Jaana Salmensivu (Chapter 4); Trainee Riikka-Mari Vehmanen; Scientific Secretary Helena Vänskä (Chapter 3). The project group's secretary was Marjukka Terho. The report has been translated from Finnish into English by David Kivinen. Tuulikki Toivonen and Anu Kukkonen have assisted in proofreading. The final report was compiled and edited by Kai Husso, Sakari Karjalainen and Tuomas Parkkari.

1 Science policy and scientific research: a changing environment

Science policy and the environment of scientific research have changed quite considerably in recent years, not only in Finland but in many OECD countries. This Chapter provides an overview of these changes and examines the national innovation system in Finland, the political expectations attached to the system and the collaboration among the organisations involved from the point of view of scientific research and universities. At the same time, the Chapter serves as a general introduction to the rest of the report.

Universities and scientific research are key elements of the *science system* and an integral part of the *national innovation system*. The hard core of the science system consists of universities and research institutes, but it also comprises companies with R&D operations as well as government organisations responsible for science and technology policy. The innovation system additionally comprises business and industry more generally as well as all the economic structures, political organisations and institutions that have a direct or indirect impact on research[1]. During the 1990s, science and innovation systems have come under mounting economic and social pressures of change in all OECD countries, mainly with respect to their performance, efficiency and impact. This trend has been influenced by two closely related factors, or what might be termed as two megatrends in the R&D environment.

First, it has been shown in numerous scientific studies as well as in various European Commission and OECD reports that research has a clear positive impact on economic success, welfare, competitiveness, and innovativeness (see European... 1997; National... 1998; Technology... 1998). On the strength of this evidence there has been growing support for the view that research represents a major strategic resource with respect to industrial, economic and social development.

Another trend that has clearly influenced R&D and its environment is globalisation and the related development of market economy. Key factors in this regard are international business, competition and trade, which rely heavily on the creation and use of new technology and on the ability to adopt and apply new information (e.g. Technology... 1998; Managing... 1999).

The analysis of globalisation often tends to revolve around the structures and the operation of the economy. Globalisation may be interpreted in terms of an expansion and deepening of market relations both within and between states. At the same time, it is felt the process of globalisation has become so independent of national organisations that it can be used to explain changes in state institutions, their operation and structures. Closely related to this trend in development are new forms of collaboration and the operation of state political systems, which are aimed at broader harmonised

1 A more detailed analysis of the national innovation system should also look at how R&D activities are related to the production system, to the operation of markets and to different political sectors (e.g. employment, economic and trade policy). However, these aspects are excluded from the present discussion.

markets and economic-political units (e.g. Väyrynen 1998, 1999; Alasuutari & Ruuska 1999).

International co-operation is an important part of scientific research, and has always been so. With the ongoing process of globalisation the traditional functions of science and education in universities have assumed new goals and new perspectives. As far as scientific research is concerned, globalisation has created new opportunities for closer and more diverse forms of international collaboration. This may significantly improve prospects for the production and dissemination of new scientific knowledge, for new scientific breakthroughs, for new applications of knowledge, and for the promotion of welfare in modern society.

Knowledge and know-how are increasingly important to the production of goods and services. On the one hand production is highly research-intensive, based as it is on the efficient use and application of scientific knowledge; on the other hand it is technology-intensive, drawing on the extensive utilisation of new technology and on the mastery and development of the knowledge base of complex production processes. Research, technology, innovations and, particularly, their relationships have taken on new political and economic meanings and emphases. Knowledge and innovativeness are currently at the centre of much attention both at home and abroad: these are the key factors in global competition that are the focus of development efforts in several political sectors. Finland's response to the challenge came in the mid-1990s in the form of a national development strategy ('A Knowledge-based Society') aimed at the promotion of economic growth, employment and welfare. Among the key elements of this strategy are the national innovation system as introduced by the Science and Technology Policy Council, as well as the political measures related to the development of this system. It is stressed that innovation depends on both scientific research and technological development as well as on the ability of the organisations involved to work closely towards a common set of goals.

1.1 Scientific research and universities in the national innovation system

In recent years, the role of governments and government policies (including science policies) has changed considerably. Today, the output and impact of research are under closer scrutiny than ever before. The new role of the public sector is also seen in the growing efforts by political means to encourage multilateral co-operation among the organisations involved in the national innovation system. Among the issues that have received special attention are the obstacles to the broader dissemination, introduction and application of information and technology, which adversely affect the utilisation of research both at home and abroad. National policy-making and decision-making also takes closer note than before of trends and development on the international scene.

In practice, the weight of science policy and its relation to technology policy and to the national innovation system is determined within the Science and Technology Policy Council. The Council aims to take a broad and comprehensive view on all issues under its jurisdiction, looking upon different political sectors as interactive elements constituting an integral part of a larger whole. In the Council's 1996 report, the main goals set for the national innovation system (and by the same token for science policy) were as follows: 1) to carry on with the large-scale development of the innovation system, an effort which was started in the early 1990s; 2) to further develop and deepen co-operation and interaction between different components of the innovation system and political sectors; 3) to develop the science system, research environments and education; 4) to deepen international science and technology co-operation; 5) to intensify the utilisation of knowledge and know-how by means that serve the best interests of business companies, individuals (improving individual skills) and society at large; 6) to increase research funding so that the *R&D intensity* (i.e. the GDP share of R&D expenditure) in 1999 stands at 2.9 per cent (Finland... 1996).

A key factor with respect to the rapid increase in R&D funding was the Cabinet Economic Policy Committee decision in 1996 to raise the level of the Government financing of R&D by a further FIM 1.5 billion (EUR 252 million) by 1999 (compared to the level of the 1997 budget appropriations). All in all, the amount of total additional R&D funding from 1997 to 1999 was some FIM 3.4 billion (EUR 565 million). The aim was to strengthen the whole R&D system and get it working more effectively for the national economy, business and industry and employment. In science policy terms, the essential element in the Government's additional funding program was that it aimed at strengthening high-quality research in the fields of engineering and natural sciences, and in the fields relevant to information- and technology-intensive business. Although the accent was clearly on applied research and product development, some 40 per cent of the additional funding was allocated to universities, either directly or through the Academy of Finland. The goal of raising the level of R&D intensity was achieved, so, in this sense, the national project to put Finland at the forefront of international R&D investment was successful.

There is a broad consensus of opinion in Finland about the general goals and objectives of the national innovation system. It is agreed that knowledge and know-how are crucial to economic growth, employment and social welfare, paving the way to a higher standard of living and to intellectual growth. It is for this reason that every effort is made to promote the development and utilisation of knowledge and know-how on as broad a basis as possible. However, views on the more specific goals and political objectives of the innovation system have tended to be somewhat divided: the innovation system has been seen either as a useful perspective on the development of science and technology policy, or as a manifestation of a narrow-minded concept of science (e.g. Allardt 1997, 1998; Häyrinen-Alestalo 1999).

The debate waged on the role of research and universities ties in closely with the science policy lines and the development and problems of that policy. Another issue that is often raised in this connection is how to maintain the distinctiveness and identity of different components of the innovation system (such as universities) if the main effort is to develop and improve the 'innovation machinery' as a whole, under one umbrella concept. The risk is that any individual components whose goals are not in line with the ultimate objective of the system, i.e. innovation, may lose their position and significance.

Indeed, science policy should be approached from three different angles. It should be developed, first, as a separate policy sector; second, in conjunction with technology policy, aiming to establish a free-flowing dialogue; and third, as part of the national innovation system and its broad perspective. Science and technology policy, for instance, should be developed when there are common interests at stake, or when decisions are required on mutual co-operation or a division of labour. This would at once make it easier to strike a balance between scientific relevance and industrial – and, in a broader sense, societal – relevance. However, as far as the innovation system is concerned, it is important that sufficient scope is allowed for the independent development of science policy and the science system and for their own objectives. If they are deprived of that independence, tensions may begin to creep into the development of science policy and the innovation system which eventually will give rise to political competition and the adverse consequences that inevitably follow.

1.2 Changes in research resources in the 1990s

With few exceptions the changes that have taken place in the Finnish research environment during the 1990s have been very similar to those experienced in other Western industrial countries. According to OECD reports, the main trends that have affected universities in recent years have included: 1) a decline in government R&D funding; 2) a decline in the share of the Government sector in the total R&D funding; 3) a change in the nature and allocation criteria of public funding; 4) closer internal integration within the innovation system and increased co-operation among organisations; 5) continued structural and operative reform of science and national innovation systems; 6) increased co-operation within and between universities; 7) increased international interaction in research; 8) growing concerns about the quantity and quality of research personnel (e.g. University... 1998; Technology... 1998).

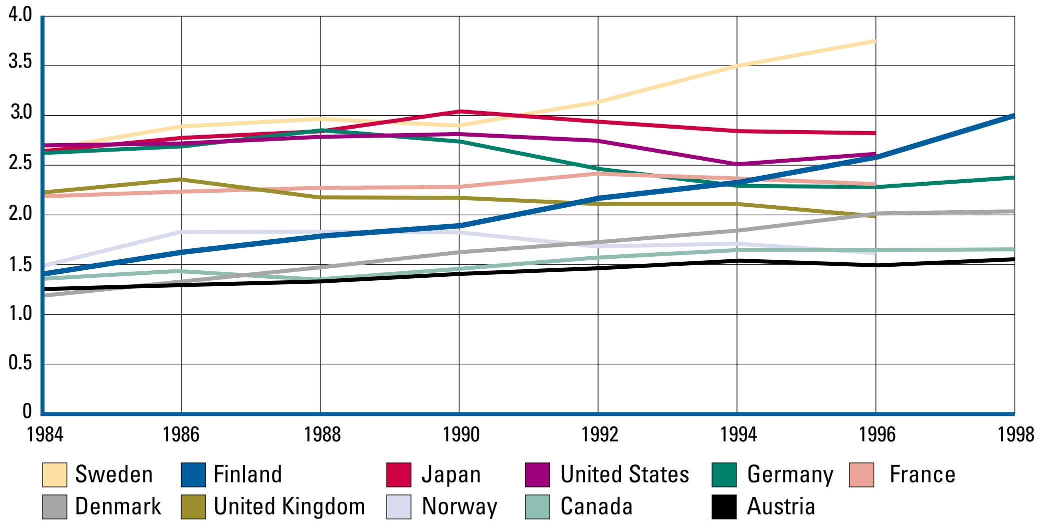
Trends in the allocation of research resources have varied considerably in different OECD countries during the past couple of decades (see Figure 1.1). In the late 1980s, the volume of research funding and R&D intensity both showed an upward trend in all OECD countries. This trend began to slow down in the early 1990s, and at the same time there were some signs of growing divergence between different countries. Finland has been heading in the opposite direction to many major industrial countries such as the United States, Japan, the United Kingdom and France: in the 1990s, Finland has ranked among the top four OECD countries in terms of R&D intensity growth (together with Ireland, Korea and Sweden). In 1997[2], Finland showed the R&D intensity of over 2.7 per cent, while the average for all OECD countries was 2.2 per cent and for EU countries 1.8 per cent (Main... 1998, 1999; OECD... 1999). The only countries ahead of Finland in 1997 were Sweden, Japan, Korea and Switzerland. According to the estimates by Statistics Finland, in 1999, Finland's R&D intensity was at around 3.1 per cent. If this remains the final figure, Finland will probably rank second in the whole world after Sweden.

In 1991, universities accounted for 22.1 per cent of the total R&D expenditure in Finland, which corresponds to the international average. By 1997, the figure had dropped to 17.7 percent[3]. In the OECD group, the only countries where universities had

2 At the time of writing this was the latest year for which comprehensive OECD data were available.

3 If research expenditure by university hospitals is included, the figure is 20 per cent. Statistics Finland included hospitals in its calculations for the first time in 1997. The sharp increase in research expenditure in the university sector in 1995–1997 is partly explained by this statistical revision. In 1998, universities' share (excluding hospitals) of the total R&D expenditure declined to 17.2 per cent, and preliminary estimates for 1999 indicate a further decrease to around 16 per cent.

■ Figure 1.1. R&D intensity (i.e. R&D expenditure as a proportion of GDP) in selected OECD countries in 1984–1998 (%).



Source: OECD, Main Science and Technology Indicators.

a smaller share of all research funding were Japan (14.3%), the United States (14.4%) and France (17.2%). Currently, in most OECD countries, universities account for between 15 and 30 per cent of the total R&D expenditure. The figures tended to rise steadily in the 1980s, but since then they have mainly remained unchanged or even dropped to some extent. Indeed, there is now growing concern in universities about the balance of and between science system and national innovation system, not only in Finland but also in the United Kingdom, the Netherlands and Germany, for instance (e.g. Dutch... 1999; First... 1999; Weaknesses... 1999; MPs... 2000). As for total research expenditure in the university sector in 1991–1997, the figures have increased most in smaller countries and in countries with a lower level of R&D intensity, such as Greece (averaging 15% a year) and Ireland (13%). In Finland, university research expenditure increased by an average 6.4 per cent a year in 1991–1997, which was slightly above the average for the OECD countries.

The OECD stresses in its recent report *The Management of Science Systems* (1999) that it is crucially important for universities to get more public funding in the future, or at the very least that this funding and overall government support will be maintained. On the basis of the most recent data for the late 1990s, model cases in this respect are Denmark, Iceland, Japan and Finland. Finland's success in this analysis was no doubt largely attributable to the Government's additional funding programme and to the rapid increase in extramural financing for universities. In its recommendations the OECD also drew attention to the balance between *basic* or *sure funding*[4] and *precarious resources*

4 The OECD report uses the terms *sure*, *core*, *precarious* and *contract-based* research funding. The first two terms refer mainly to direct funding for universities granted from the Government Budget, i.e. research financed from *public general university funds* (GUF). They are the funds which universities allocate to R&D from the general grant they receive from the Ministry of Education (or from the corresponding authority) in support of their overall research and teaching activities (see OECD... 1999; The Management... 1999).

for university research. For future stability some 70 per cent of university research funding should come from secure sources, the remaining 30 per cent should consist of external sources (e.g. commissioned research, financing from companies and, in general, research financed from other sources than core funding[5]). When we look at the situation in the mid- and late 1990s and from the viewpoint of R&D expenditure, only eight OECD countries (including Germany, Austria, Switzerland and the Netherlands) met this criterion in pure sense. In Finland, *core funding* in 1991 accounted for 67 per cent of the research expenditure of universities, in 1998 for 54 per cent (see Tutkimus-… 1993, 1999).

In an international comparison, the total R&D funding in Finland has shown quite a healthy development, at least in quantitative terms. As regards university research expenditure, the recent trends may be described as moderate, representing the average for OECD countries[6]. With the exception of the remarkable increase in government R&D funding, Finland has recently been moving closer to the science and technology policy lines adopted in the major R&D-intensive OECD countries. A key factor in this regard is that Finnish research has become more and more closely integrated with the international science system during the past 15 years. Finland is currently involved in several international research organisations (e.g. ESA, EMBL, CERN) and EU research programmes. In addition, Finnish researchers have visited foreign countries to an increasing extent, and new agreements on researcher exchange programmes have been signed.

The challenge for universities today is to develop their operation as an integral part of the science system, as part of the public sector and as part of the national innovation system. Although there is of course some overlap in terms of these development requirements, they are not always easy to fit together. The main source of difficulty is the contradiction between the outside steering of universities and the science system, on the one hand, and the internal values and objectives of scientific research, on the other. Some steps have been taken to strengthen the autonomy of universities with a view to supporting the development of research and education. However, the greater autonomy that universities enjoyed in the 1990s really was not of very much use because at the same time core funding was cut in both absolute and relative terms (as a proportion of total research expenditure). Indeed, it is important to emphasise that the amount of core funding made available to universities and the continuity of that funding are among the most critical factors with regard to improving their prospects of meeting the challenges presented to them.

The chapters below proceed to look at how the Finnish science system has changed during the 1990s and to discuss some of the key issues that have been raised in the debate on science policy. For instance, university departments and faculties have been closed down and merged, at the same time as multidisciplinary research units and

5 In this report, the term *core funding* refers to the GUF (see Footnote 4).

6 It is important to stress that since 1997 (the last date for which comparative statistics are available), funding for university research in Finland has developed quite favourably. For instance, in 1998, university research expenditure was in real terms 11 per cent higher than one year previously. If more recent international statistics were available, they would probably indicate a comparatively strong increase for university research expenditure in Finland compared to other OECD countries.

research centres in science parks have been set up. In science policy terms, the key innovations have included the launch of the centre of excellence programme and the graduate school system, the introduction of core facilities services for major research programmes, the development of professional research careers and changes introduced in the structures and allocation criteria of research funding (e.g. Tutkimusedellytys-työryhmä... 1998). To some extent the changes have met with quite a critical response in universities. Nonetheless the changes have certainly helped to improve the organisation and efficiency of research and supported the development of creative research environments, which has been considered a positive trend in all universities. However, it is still too early to assess the long-term impacts of the reforms on the development of the science system as a whole or on conditions for doing research in different disciplines.

2 Research funding as an instrument of science and innovation policy

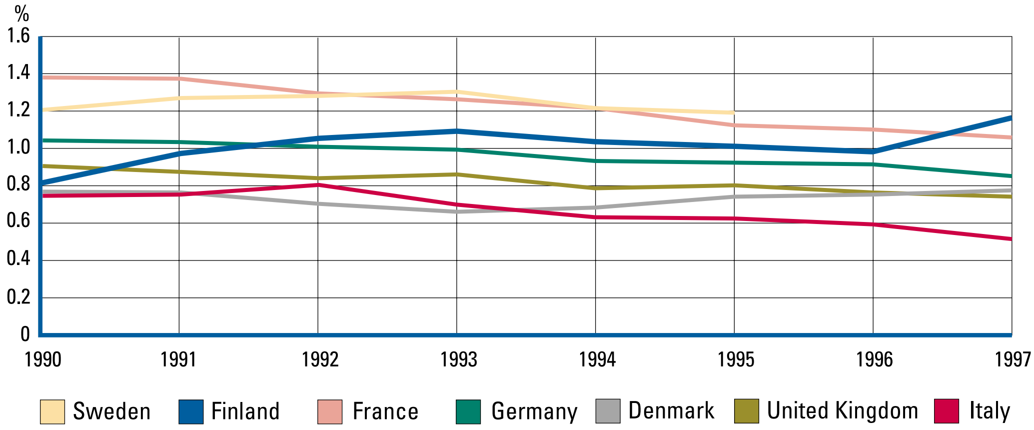
In order to function properly, science systems need to be supported by adequate and properly allocated funding. Selective allocation of funding is crucial to ensuring the highest possible quality standards of research and to strengthening the structural development of the science and innovation system. The development objectives for the Finnish innovation system in the latter half of the 1990s were related first and foremost to the extent of the system, its quality and relations of co-operation. The aim has been to put Finland at the international forefront in terms of research funding, to promote the development of the science system by increasing the amount of competitive funding and in various ways to encourage the formation of networks among different actors within the system. International competition in different fields and globalisation are putting national innovation systems under mounting pressures of continuous development. Stagnation would immediately and inevitably have adverse effects on one's relative position.

Finland is not in a position to compete with other nations of the world in terms of the absolute volume of its research funding or research outputs. The total amount of funding in the Finnish R&D system corresponds to less than two per cent of the funding made available to research in the United States. This is acknowledged by the Science and Technology Policy Council. The objective of public research funding in Finland is to develop the national research and innovation system by means of a high relative input and a careful allocation of research funding: this is considered the best way to promote the qualitative development of research and to strengthen the impact of the innovation system in society. National science policy is still an important instrument in the creation of favourable conditions for scientific research, national welfare and economic competitiveness, in spite of the increasing internationalism of research and the innovation system.

In the 1990s Finland has followed a different path from other OECD countries. In most OECD countries the increase in R&D funding has either stagnated or even started to decline. In the years that followed the deep recession which swept across Finland in the early 1990s, economic and social policy in the country has rested on a strategy of 'knowledge and know-how'. This has been reflected in heavy investments in research and development. During the latter half of the 1990s, public funding for R&D has increased from around FIM 5.5 billion to FIM 7.6 billion (EUR 1 = approx. FIM 6). At the same time government expenditure in general has been significantly cut.

In 1996, the target was set to increase the *research intensity* (R&D expenditure as a proportion of GDP) in Finland to 2.9 per cent by 1999. The goal of the Government's additional funding programme was to raise the level of Government financing of R&D by FIM 1.5 billion by 1999 (compared to the level of 1997 budget appropriations). The target for research intensity was reached ahead of schedule in 1998. The reason why this target was reached so quickly was that R&D investment in the private business sector increased faster than had been anticipated. The main contribution came from the electronics industry. Total nominal R&D expenditure doubled from FIM 10 billion in

Figure 2.1. Public funding for R&D as a proportion of GDP in selected EU countries in the 1990s (%).



Source: Eurostat.

1991 to FIM 20 billion in 1998. At the same time, research expenditure in private companies increased from FIM 5.8 billion to 15.5 billion, with the figures for the electronics industry rising from 1.5 billion to 6.8 billion. Public R&D funding has also increased very rapidly and in a quite exceptional way, which is clearly seen in a comparison of public research expenditure in the EU countries as a proportion of GDP (Figure 2.1).

Finnish science and technology policy has attracted widespread international attention, and the country's science and innovation system has been described as highly efficient. In a report published by the OECD in 1998, the Government's additional funding programme for 1997–1999 is mentioned as one of the most significant science and innovation policy initiatives in the OECD countries of recent years. Assessing the general organisation of the system, its funding mechanisms and the collaboration between the research community and industry, the OECD describes the Finnish science and research system as an example of a well-organised science and innovation policy. According to the 1999 report of the International Institute for Management Development (IMD), co-operation between universities and private business is an important national strength. The Finnish system of research funding and science policy was also positively reviewed in 1998 by the prestigious science magazine *Nature*.

The discussion below looks at how Finnish science policy has sought to respond to the challenges presented over the past decade by the internal development of scientific research, the growing role of knowledge in post-industrial society and its production structures, the globalisation of the world economy and the global ecological problems brought about by environmental change. In spite of severe economic recession in the early 1990s, research funding remained strong in both the public and private sector. There is an exceptionally strong faith in Finland in the role of knowledge and know-how as future national assets.

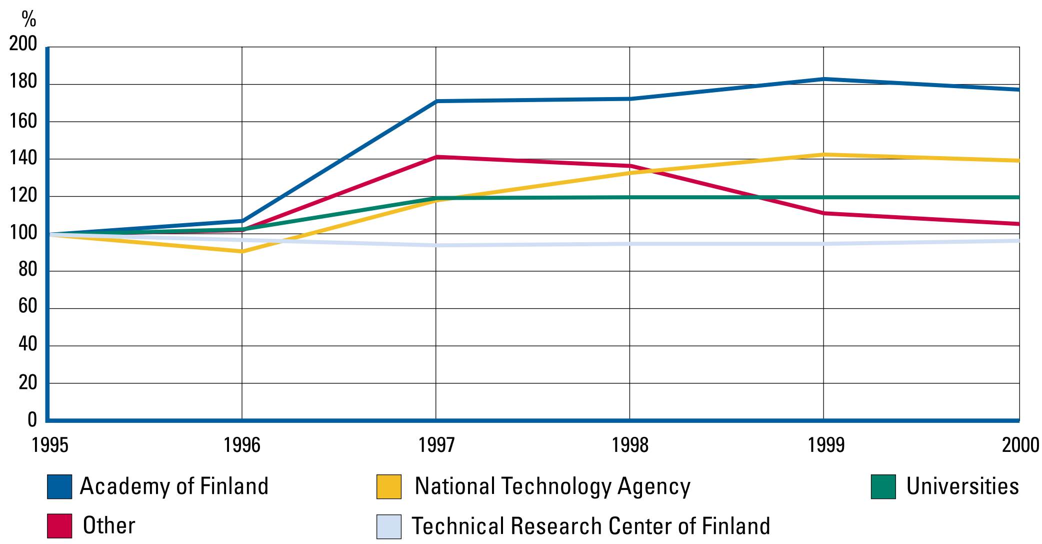
2.1 Developing the Finnish science system

2.1.1 The role of competitive funding

One of the ways in which Finland has sought to improve the quality of its research has been to increase the share of competitive research funding. This has been done by allocating a larger share of public research funds through the Academy of Finland and the National Technology Agency Tekes. The agency that saw the fastest growth in its research resources in 1995–2000 was the Academy of Finland: during this period the Academy's funding volume increase by almost 80 per cent in real terms (see Figure 2.2). During the same period funding allocated through Tekes increased by around 40 per cent. In value terms, however, the increase in Tekes funding was significantly greater than the increase in Academy funding. In 1995, funding from Tekes exceeded FIM 1.5 billion, in 2000 the figure stands in excess of FIM 2.4 billion (EUR 403 million). The corresponding figures for the Academy were FIM 460 million (1995) and FIM 910 million (EUR 153 million) (2000).

Core budget funding for universities also increased during the latter half of the 1990s. However, there was no significant net increase in the amount of research funding proper because part of the monies were now earmarked for real estate expenses, which universities did not formerly have to cover themselves. According to a Ministry of Education working group these expenses accounted for over 20 per cent of the monies received from budget sources in 1997. It seems that the share of these costs has now stabilised at this level.

Figure 2.2. Relative change in core funding for R&D in real terms in 1995–2000 (%) (index 1995 = 100).



Source: Kolu 2000.

Core funding for government research institutes remained more or less unchanged during the latter half of the 1990s (Figure 2.2). The increase in other research expenditure in 1997 is explained by the new way of budgeting special state subsidies allocated for research purposes in central university hospitals (so-called 'evo' funding), which brought an increase in research funding of around FIM 350 million.

The decrease in other research expenditure in 1999 was in turn due to the reorganisation of the State Real Estate Board as a public utility, which meant that the Board's expenditure items were removed from the budget. For this reason real estate investment expenditure by universities and research institutes, which was formerly included in the budget as a separate item, was now removed and universities and research institutes were required to secure the necessary funds through their own core funding.

The shifting emphasis in research financing from basic funding for universities and research institutes to funding allocated through the Academy of Finland and Tekes has improved the availability of competitive funding. In the Academy's case this is reflected in a growing number of accepted applications and in a growing amount of funding granted as a proportion of applications received. In 1995, funding awarded by the Academy stood at around 14 per cent of the total sum applied for; the corresponding figure in 1999 was 23 per cent. Statistics are not available for Tekes, but at least in the short term it is clear that the changes must have had a similar impact. As soon as the science system expands in response to the increased availability of funding, there is bound to be more intense competition for funding as well.

2.1.2 Developing international research co-operation

One of the most important objectives in the development of the science system in the latter half of the 1990s was to promote international research co-operation. Key areas in this development effort included research co-operation in the European Union as well as with national science institutions in Europe. Efforts were also stepped up to increase bilateral research co-operation among others with the United States, Japan, Russia, and emerging Asian states.

Internationalisation is an integral part of the science community's norm system. Key areas in this respect have included the signing of new agreements of co-operation, involvement in international research programmes and the promotion of international mobility among researchers. In many fields the research community is now genuinely international, so that all communication and scientific reporting takes place in a major world language. In this situation the national role of researchers is particularly one of popularising the results of scientific research, of working in university education and of working closely with other actors in society to help make the best possible use of research results.

International mobility of researchers

In all fields of research scientific collaboration and exchange consists not only of international publishing and participation in conferences, but also of work in foreign countries. During the latter half of the 1990s the total annual duration of international visits by Finnish researchers was about 840 person-years. On the basis of the average size of grants awarded by the Academy of Finland for researcher exchange, the value of this international mobility was around FIM 100–130 million a year. No detailed figures are available on the investments made in researcher exchange because the monies come from many different sources. For instance, many private foundations make a significant contribution in this area.

The Academy of Finland is a major source of funding for international researcher exchange. In 1999, the Academy had bilateral agreements with 33 scientific organisations in 26 countries. During the 1990s the Academy signed agreements on bilateral researcher exchange with 12 countries. Nine of these agreements were entirely new, three were revised as a result of political changes. Among the most significant new openings are the agreements signed with the Asian countries of South Korea (1997) and Taiwan (1998). New forms of bilateral international co-operation include collaboration in evaluation projects and joint research programmes.

In 1999, the Academy spent a total of FIM 29 million on bilateral researcher exchange and on supporting researchers working abroad; the figure was the same in 1995. In addition, the Academy has other forms of funding to support researcher mobility. In 1998 travel expenses accounted for FIM 37 million of all supported projects; this sum does not include wages and salaries for travel time. Some support for researcher mobility is also provided through the Centre for International Mobility (CIMO).

A survey conducted in conjunction with the round of applications invited by the Academy of Finland in 1998 for prospective centres of excellence showed that key partners in co-operation for Finnish researchers are the United States, Canada, China and Russia as well as Germany, the United Kingdom and Sweden. There has been less success is establishing contacts with Japan at the level of individual researchers. Increasingly, Finnish researchers are now moving to work in European countries. Part of the explanation lies in the increased involvement of Finnish researchers in EU research programmes.

Finland in EU research programmes

Finnish involvement in EU research programmes has been the most significant trend of internationalisation in research during the latter half of the 1990s. The country's involvement in individual projects and programmes began in 1987. Since Finland joined the Union as a full member at the beginning of 1995, participation in EU framework programmes has become an integral part of the country's science policy. These programmes have assumed ever greater importance in the development of research organisations and collaboration with the business sector. According to the OECD, EU framework programmes have been highly successful in establishing closer links of co-operation between the research sector and industry: to date they have created 150,000 such links in different European countries. European universities have benefited from this trend in development to a greater extent than government research institutes.

Universities and research institutes in all OECD countries have seen a decrease in the amount of direct budgetary funding from the public purse. At the same time, extramural funding has continued to gain more and more importance. Funding from the EU is one of the significant sources. The large volume of monies involved means that it provides ample opportunities for research teams engaged in the fields that are supported through the framework programmes. On the reverse side of the coin, the opportunities offered to universities or research institutes mean that their research resources are tied to EU projects. However, it is unlikely that these kinds of problems will represent a very major difficulty in a highly expansive science and innovation system such as Finland's.

Finland's imputed contribution to the Fourth Framework programme was EUR 185 million. At the same time, Finnish researchers received funding worth over EUR 200 million for their projects in 1995–1998[1], i.e. slightly more than Finland paid out to the EU. The bulk of these projects have been jointly funded, for which the EU provides a maximum of 50 per cent of the total project budget. On this basis we may estimate that in addition to the national contribution, at least FIM 1.1 billion (EUR 185 million) has been invested in EU projects during the same period of time, i.e. over FIM 250 million annually. Overall then, the costs of EU research programmes during the Fourth Framework programme have totalled around FIM 500 million a year.

Finland has also received funding for R&D purposes through the EU Structural Fund. In 1999, the support was worth an estimated FIM 80 million. Spending in EU research has accounted for less than 10 per cent of annual public R&D expenditure.

Involvement in international science organisations

Involvement in international science and research organisations is another important avenue of international co-operation. In disciplines which require major basic investments and infrastructures, international co-operation is in fact essential. Funding for international co-operation consists in large part of membership fees.

The major membership fees go to the European Organization for Nuclear Research (CERN) and the European Space Agency (ESA): in 1995, the fees amounted to around FIM 52 million. In addition, Tekes awarded a total of FIM 86 million to support participation in ESA research programmes in 1995. Part of these monies returned to Finland in the form of orders worth over FIM 50 million. In 1999, a total of FIM 60 million was earmarked for these two membership fees, and Tekes granted FIM 55 million to support participation in ESA programmes. In 1995, a total of FIM 5.6 million and in 1999 FIM 3.7 million was granted for supporting the European Molecular Biology Laboratory (EMBL) and the European Molecular Biology Conference (EMBC). The Academy of Finland pays out a total of FIM 10 million a year in other membership fees for international scientific co-operation. In 1995, a total of some FIM 150 million and in 1999 FIM 120 million were allocated to international co-operation through the organisations mentioned above, i.e. roughly the same amount as is granted for the promotion of international researcher mobility.

2.1.3 Developing creative research environments

Centre of excellence policy

The general objective of science policy in Finland is to raise the quality of scientific research and to improve its international competitiveness, visibility and esteem. There are a number of countries around the world that have a policy of investing public research funding in a centre of excellence system. More and more often, research groups in centres of excellence are multidisciplinary teams that may also operate in a virtual fashion as

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1 The data for 1995–1998 are drawn from a survey by Pirjo Niskanen and colleagues (1998) from the Group of Technology Studies at Technical Research Centre VTT. The statistics for 1998 are incomplete, especially for funding granted towards the end of that year.

umbrella organisations. In line with the objectives set out by the Science and Technology Policy Council, the Academy of Finland has invested part of the funds made available to it through the additional funding programme since 1997 to strengthening existing centres of excellence in research and to creating new centres. Ultimately the centre of excellence policy is aimed at developing creative research environments. The centre of excellence policy can be expected to have far-reaching consequences primarily in terms of raising the quality of scientific research but also in bringing basic research and applied research closer together and in producing new innovations that in the long term will have significant commercial and social applications.

One of the criteria adopted by the Ministry of Education in 1994 for the allocation of performance-based funds was the status of centre of excellence. The Academy of Finland was asked to propose candidates for centres of excellence in Finnish research. On this basis of this proposal the Ministry awarded the status of centre of excellence to 12 research units for 1995–1996 and for an extension period 1997–1999 (Table 2.1). In addition, the Ministry of Education nominated five new centres of excellence in 1996, again on the basis of the Academy's proposals, which started their three-year term at the beginning of 1997. In 1995–1999, universities hosting centres of excellence were granted FIM 38–48 million a year in performance-based funds. The centres of excellence varied considerably in size: there were three comparatively large umbrella organisations that were engaged in cell and molecular biology research; on the other hand the smallest centre of excellence had a staff of no more than 12. In 1996, the Academy accounted for an average one-quarter of the total funding for centres of excellence, but the share varied quite widely from 10 to 45 per cent.

Initially the centres of excellence in research were simply awarded the status, but no separate funding. However, the amount of support they have received through the Academy in the form of competitive funding has been quite considerable. In 1997, the Academy made funds available for hiring 44 postdoctoral researchers in centres of excellence. Out of the additional funding programme the Academy allocated a total of FIM 51 million to centres of excellence. The 12 centres that started their term in 1995 received FIM 18 million for 1998 and after an interim assessment a further FIM 18 million for 1999. The five centres that started in 1997 received a total of FIM 15 million for 1998–1999.

The national centre of excellence strategy published in 1997 was formulated by the Ministry of Education, the Academy of Finland, the National Technology Agency Tekes and business and industry as well as representatives of universities. A total of 166 research units aspiring to the status of centre of excellence submitted their plans of intent, 51 went through to the second round and an international evaluation. At the end of 1998, the Academy nominated 26 units into the centre of excellence programme for 2000–2005 (Table 2.1). Some of the centres from 1995–1999 continued in the new programme, albeit in most cases with different team compositions and research plans.

The centres of excellence nominated were research and researcher training units consisting of one or more high-quality research teams with clear, common research goals and representing the very highest level of expertise internationally, or with good

Table 2.1. Centres of excellence in research 1995–1999, 1997–1999 and 2000–2005.

Centres of Excellence in Research 1995–1999
Biocenter Oulu: University of Oulu
Cognitive Brain Research Unit: University of Helsinki
Hereditary Disorders Research Unit: University of Helsinki
Laboratories of Compound Semiconductor Technology and Surface Science: Tampere University of Technology
Low Temperature Laboratory: Helsinki University of Technology
Multilingual Language Technology Unit: University of Helsinki
Neural Networks Research Centre: Helsinki University of Technology
Research Team for Biblical Exegetics: University of Helsinki & Åbo Akademi University
Research Team for Ecology and Animal Systematics: University of Turku
Research Team Investigating Climatic Change, its Silvicultural and Economic Implication in Forestry: University of Joensuu
Research Unit on Economic Structures and Growth: University of Helsinki
Turku Centre for Computer Science: University of Turku, Åbo Akademi University & Turku School of Economics and Business Administration
Centres of Excellence in Research 1997–1999
Biocentrum Helsinki: University of Helsinki
BioCity-Turku: University of Turku & Åbo Akademi University
Department of Ecology and Systematics, Division of Population Biology: University of Helsinki
Digital Media Institute: Tampere University of Technology
Human Development and its Risk Factors Programme: University of Jyväskylä
Centres of Excellence in Research 2000–2005
Ancient and Medieval Greek Documents, Archives and Libraries: University of Helsinki
Cell Surface Receptors in Inflammation and Malignancies: University of Turku
Center for Activity Theory and Developmental Work Research: University of Helsinki
Center of Excellence in Disease Genetics: University of Helsinki, National Public Health Institute & Folkhälsan
Computational Consended-Matter and Complex Materials Research Group (COMP): Helsinki University of Technology
Evolutionary Ecology: University of Jyväskylä
Formation of Early Jewish and Christian Ideology: University of Helsinki & Åbo Akademi University
Human Development and Its Risk Factors: University of Jyväskylä
Institute of Hydraulics and Automation (IHA): Tampere University of Technology
Low Temperature Laboratory: Helsinki University of Technology
Metapopulation Research Group: University of Helsinki
Molecular Biology and Pathology of Collagens and Enzymes of Collagen Biosynthesis: University of Oulu
New Information Processing Principles: Helsinki University of Technology
Nuclear and Condensed Matter Programme at JYFL: University of Jyväskylä
Plant Molecular Biology and Forest Biotechnology Research Unit: University of Helsinki
Program in Cancer Biology. Growth Control and Angiogenesis: University of Helsinki
Program on Structural Virology: University of Helsinki
Programme of Molecular Neurobiology: University of Helsinki
Research Centre for Computational Science and Engineering: Helsinki University of Technology
Research Unit for Forest and Ecology Management: University of Joensuu
Research Unit for Variation and Change in English: University of Helsinki
Signal Processing Algorithm Group (SPAG): Tampere University of Technology
Structures and Catalytic Mechanisms of Membrane Proteins: University of Helsinki
Tissue Engineering and Medical, Dental and Veterinary Biomaterial Research Group (BRG): Tampere University of Technology, University of Helsinki & Helsinki University of Technology
VTT Industrial Biotechnology: Technical Research Centre of Finland
Åbo Akademi Process Chemistry Group (PCG): Åbo Akademi University

prospects of reaching the international forefront. The centres of excellence are based at universities and research institutes. The units vary in size: the average number of staff is 53 (range 13–108), with women accounting on average for 44 per cent of personnel (range 4–74%). The average number of research staff is 50 (range 16–113). On average 50 per cent are supervisors (range 31–93%), the rest are doctoral students.

The resources of the funding bodies and the host organisations were pooled to achieve the common goals. The negotiations involved the management of the unit in question, representatives of the host organisation, the Chair of the relevant Research Council from the Academy of Finland and people from its Administrative Office, and in some cases also representatives of Tekes and business and industry. The final funding decisions were made following negotiations in spring 1999.

In 2000–2002, the Academy of Finland will be supporting 26 centres of excellence with grants worth FIM 126 million; the contribution of Tekes amounts to FIM 31 million. It was also agreed that the host organisations will allocate FIM 288 million to secure basic funding for the centres of excellence. Additionally, universities decided on the basis of these negotiations to allocate FIM 74 million out of the performance-based funds they had received from the Ministry of Education to centres of excellence in research. All in all funding decisions worth around FIM 519 million were agreed upon in connection with this round of negotiations for the period from 2000 to 2002.

In addition to direct funding allocated to supporting centres of excellence in research, funds were also made available for core facilities shared by these centres and other high-level research teams. Seven core facilities organisations were awarded funding worth FIM 164 million for 2000–2002. The host organisations will cover FIM 143 million of these expenses, the Academy of Finland's share is FIM 21 million.

Most centres of excellence receive funding from other sources as well. Funding through EU framework programmes and other international funding is a particularly important source. Over half of the centres receive funding from the Ministry of Education to run graduate schools. Around one-quarter of the centres of excellence in research receive funding from business and industry. Non-profit foundations are a significant source of funding for around one-fifth of all centres of excellence.

Research programmes as a strategic means of funding

Academy of Finland research programmes have been an important tool in pursuing science policy objectives in key areas of research. Research programmes are launched on three sets of grounds. First, research programmes are started up in response to initiatives emerging from the evolution of scientific disciplines; the aim here is to strengthen promising new trends in basic research. Second, research programmes are set up in response to emerging needs in society; these are conducted in close collaboration with funding bodies, the end-users of research, universities and research institutes. Third, research programmes are started in disciplines where there is a commitment in research to excel and reach the highest international level. Research programmes are multidisciplinary. Their aim is to generate a measurable added value in science and research.

Research programmes run for a fixed period of time (usually three years) and ideally they involve consortia that combine several research projects. A distinction can be made between two different types of initiatives to start up Academy research programmes, i.e. bottom-up initiatives that come directly or indirectly from people in the research community, and top-down initiatives that are based on considerations of social relevance. Research Councils play a key role in this regard: some four-fifths of all initiatives leading to the start-up of a research programme come from Research Councils. The rest of the initiatives come from other sources, to some extent from outside the Academy. These initiatives are also weighed in the Research Councils on their scientific merit.

In 1998, a new type of strategic research funding was introduced in the form of targeted programmes, with funds allocated to research themes specifically designated by Research Councils. Targeted programmes are favoured ahead of research programmes when a certain field of research that requires strategic funding does not have enough research resources or competencies to run a research programme, or when the object of study lies within the confines to just one or two disciplines. Targeted programmes are also used when the projects under consideration have no essential link with one another. Targeted appropriations are granted to projects focusing on a well-defined, specific area of research, and the programmes operate on a smaller scale than research programmes proper both in terms of preparation, content area and funding volumes and in terms of administration and evaluation.

The most recent innovation related to the funding of research programmes and targeted programmes is cross-border funding co-operation. For example, 'Interaction across the Gulf of Bothnia' is a three-year research programme (2000–2003) in the humanities and social sciences that is funded from both public and private sources in Finland and Sweden. In 2000, the Academy of Finland will be inviting applications for a targeted research programme on juvenile diabetes. Funding will also be made available through the Juvenile Diabetes Foundation International in the United States and the Sigrid Jusélius Foundation in Finland.

The Academy of Finland received a total of FIM 630 million (EUR 106 million) through the Government's additional funding programme for 1997–1999. Almost 30 per cent of these monies or FIM 184 million have been invested in supporting research programmes. In 1995–1998, the Academy has each year had 13–18 research programmes under way. In 2000, four new research programmes are due to start up, with funding from the Academy amounting to FIM 157.5 million.

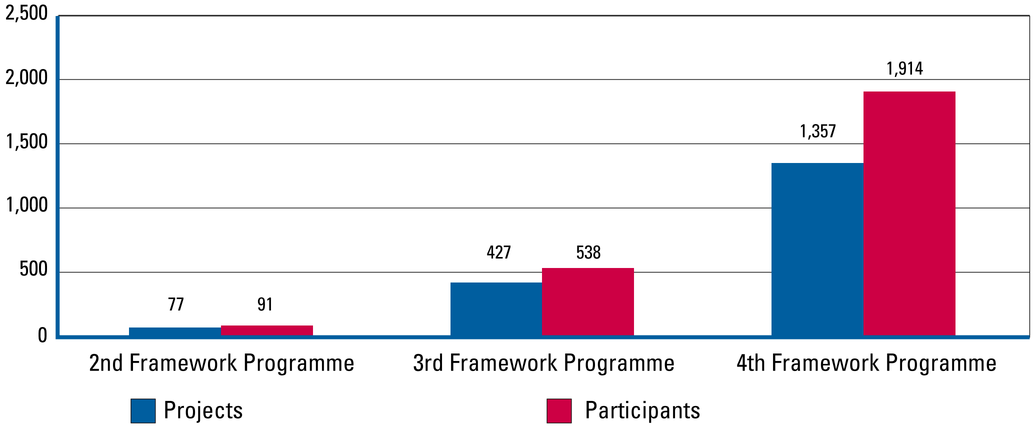
The Academy's policy with respect to funding research programmes has been to try and create bigger entities for instance by pooling resources with other funding bodies, most notably Tekes, various ministries, non-profit organisations and the Finnish Work Environment Fund. The contributions from other bodies have usually been much smaller than those by the Academy and the Technology Agency, but nonetheless significant.

In the late 1990s, the Academy of Finland and Tekes began working much more closely in the planning and co-ordination of research programmes. Total funding allocated to seven jointly administered three-year research programmes in 1995–1999 amounted to around FIM 600 million. The Academy accounted for 50.2 per cent of the funding for these programmes, Tekes for 43.4 per cent; other funding bodies accounted for the remaining 6.4 per cent. In individual research programmes Tekes' share has usually varied from around one-third to one-half of the Academy's contribution. The situation is different in national cluster programmes. For instance, in the Finnish Forest Cluster Research Programme (Forest Wisdom 1998–2000) Tekes has contributed nearly three times as much as the Academy, or FIM 75 million.

The European Union's research policy is organised into broad framework programmes that are divided into thematic and horizontal research programmes. EU research programmes are aimed at promoting economic and social development in the areas concerned on as broad a basis as possible. As well as seeking to strengthen technological know-how and economic competitiveness, the aim of EU programmes is to improve the quality of life of all people living in the Member States, to increase cohesion among Member States and to support EU policy. R&D programmes help to strengthen international and national structures of co-operation by promoting the development of networks between the people doing research and those interested in using its results. The programmes are intended for groups formed by universities, research institutes and business companies. As a rule it is required that research consortia involve independent organisations based in at least two different states.

Finnish involvement in EU research programmes has increased considerably. This is clearly seen in Figure 2.3 which describes the involvement of Finnish researchers in different framework programmes. Participation in the Fourth Framework Programme was almost four times higher than in the previous programmes.

Figure 2.3. Finnish participation in EU framework programmes.



Source: Niskanen et al. 1998.

The impact of EU research on the work that is done nationally is clearly seen in an analysis of the economic resources committed to different programme areas. Information and teletechnology and industrial and materials technology have received almost half of all the EU monies that have come to Finland. Most of the rest of the programme funding has also gone to the natural sciences and medicine. Six per cent of

Table 2.2. Funding for the EU Fourth Framework Programme.

Programme	EU ECU million	%	Finland ECU million	%
THEMATIC PROGRAMMES				
Information and Communications Technologies	3,668	27.8	68.5	32.9
Industrial Technologies	2,140	16.2	30.8	14.8
Environment	1,157	8.8	18.7	9.0
Life Sciences and Technologies	1,709	12.9	34.4	16.5
Energy	2,412	18.3	33.5	16.1
Transport	263	2.0	6.7	3.2
Targeted Socio-economic Research	147	1.1	2.5	1.2
HORIZONTAL PROGRAMMES				
International Co-operation	575	4.4	2.6	1.3
Dissemination and Optimisation of Results	352	2.7	3.8	1.8
Training and Mobility of Researchers	792	6.0	6.4	3.1
TOTAL	13,215	100	207.9	100

Source: Niskanen et al. 1998.

the monies have gone to supporting core facilities, promoting international co-operation and mobility, postgraduate training and the utilisation of research results. No more than around one per cent of the research funding received has gone towards studies of man and society. Compared with national research policy, research funded by the EU leans more clearly towards the natural sciences and technology.

The breakdown of the funding received by Finland by functions and programme areas does not differ significantly from the breakdown of EU funding overall, except in the case of information and teletechnology programmes (Table 2.2). In Finland, these two fields received a considerably larger proportion of the research funds than in the EU's framework programme overall. Most of the funding received by Finnish researchers is for thematic programmes at the expense of horizontal programmes, i.e. those aimed at the promotion of international co-operation, the utilisation of research results and the promotion of postgraduate training and researcher mobility.

Measured in terms of the number of research staff, Finnish involvement in EU programmes has been at the same level as in Sweden and Norway. The most active participants have included the smaller EU countries such as Greece, Ireland and Portugal, where public sector investment in research has been at a relatively low level. The major science countries of Europe, i.e. Germany, the United Kingdom and France, on the other hand, take part in EU projects far less frequently (in relative terms) than Finland. If involvement in EU programmes is compared to the contributions of different Member States, the country rankings are slightly different. However, the basic difference between the small and big research nations remains unchanged. This suggests that the research policies of the bigger countries are less dependent on EU's research programmes than is the case in the smaller countries. According to the OECD, the science systems in the countries of southern Europe and Ireland have clearly benefited from EU research funding, which has allowed them to develop their research infrastructure and become more closely integrated into the European research system.

However, the extent to which EU programmes influence national science policy partly depends on national decision-making. The influence of the EU will be greater if national funding bodies in their own decision-making favour research teams that are involved in EU projects. EU programmes are created through the joint efforts of the Commission and national science and technology policy actors and end-users of research. If the programmes are in line with the objectives identified in national science policies, then the EU influence is obviously less significant. The key issue here is how far individual nations have been able to influence programme agendas in the preparation of EU programmes so that they are as consistent as possible with national objectives. An example of the interaction between national science policy and EU research policy is provided by the similar emphases that are to be found in Academy research programmes and the Fifth Framework programme. The objectives of the Fifth Framework Programme are also well in line with the objectives of national science policy in Finland. It is impossible to say to what extent Finnish objectives have influenced EU decision-making and vice versa.

During the latter half of the 1990s, the Academy of Finland has joined forces with a number of other funding bodies to support six different research programmes concerned with themes that are directly relevant to the framework programme. Between 1996 and 1999, the Academy took funding decisions to support the following research programmes: 'Bioversity' (1997–2002), 'Environment and Health' (1998–2001), 'Urban Studies' (1998–2001), 'Material Science of Forest-based Products' (1998–2001), 'Global Change' (1999–2002) and 'Ageing' (1999–2002). Through these programmes research into these themes has received national funding worth FIM 270 million, of which the Academy accounts for FIM 160 million. The funds have helped to strengthen research and know-how in these fields and at the same time strengthened the position of Finnish research teams in the competition for funding within the framework programme.

2.1.4 Promoting professional careers in research

Researcher training

Researcher training in Finland received a major boost in 1994 with the Ministry of Education decision to set up a graduate school system. This decision was based on a set of proposals outlined by an Academy of Finland working group. The working group drew attention to a number of problems in postgraduate training in Finland: the age at which doctorates are obtained is very high, the amount of time that candidates spend in their postgraduate studies is too long, they do very little work abroad, the supervision they receive is clearly inadequate and they have to compete for a scarcity of postgraduate training positions.

Launched in 1995, the new graduate school system is aimed at improving the quality of postgraduate training in Finland. To this end, steps have been taken so that postgraduate students can concentrate full-time on their studies in fixed-term posts at graduate schools, with funding provided through the Ministry of Education. The funding channelled to graduate schools has also helped to improve the quality of supervision and increased international exchange in education.

The graduate schools were launched in 1995 in two phases. The first 67 schools were opened at the beginning of 1995, with funding provided for hiring 722 postgraduate students. An additional appropriation included in the 1995 budget allowed 92 new posts to be opened in existing schools in autumn 1995, and at the same time 26 new schools were launched offering 128 student places. Funding for places in graduate schools was provided for four years at a time, earmarked for this specific purpose in connection with other funding allocated to universities.

The additional funding programme adopted by the Government in 1996 for 1997–1999 included around FIM 120 million (EUR 20 million) for the development and expansion of graduate schools and for the start-up of new schools. At the beginning of 1998, 12 new graduate schools were opened with places for 96 postgraduate students. Among the existing schools, 31 received 171 new places. The priorities of the additional funding programme meant that these new places were dedicated to fields important to the development of technology, the natural sciences, and knowledge-intensive business.

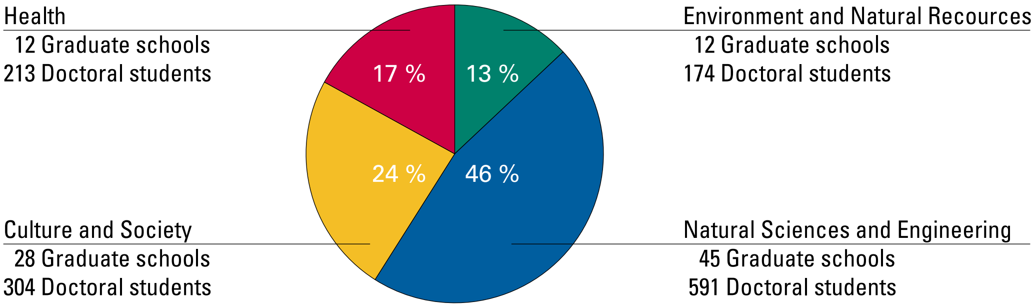
The second four-year term of the graduate schools started at the beginning of 1999. Prior to this the Academy's Research Councils gave an assessment of all graduate schools completing their first four-year term and proposals for opening new schools. This led to some reorganisation, and a small number of graduate schools were discontinued. At the beginning of 1999 there were a total of 1,282 postgraduate student places funded by the Ministry of Education. All in all, graduate schools had an estimated 4,300 doctoral students. Funding for this system is also provided by the Academy of Finland, universities and research institutes as well as non-profit foundations and international organisations.

The Academy of Finland has contributed by allocating student places and grants for organising national researcher training courses and for the promotion of mobility of doctoral students. In addition, a very considerable number of doctoral students at graduate schools are researching their doctoral thesis with project funding from the Academy of Finland. Overall Academy funding to graduate schools almost doubled during 1995–1999.

A key measure of university performance, as applied by the Ministry of Education, is the annual number of doctorates earned. These targets have been revised upwards with the development of the graduate school system. The statistics so far indicate that the system is well capable of meeting these numerical targets: in fact each year the universities have exceeded the targets. The graduate school system has created a more solid framework for scientific postgraduate training: the number of degrees awarded has more than doubled since the beginning of the 1990s. The target set for 1999 was 933, the number of students who earned their doctorate was 1,165.

One of the decisions with a key impact on the structure of the science and innovation system in the medium term has to do with the allocation of graduate schools to different

■ Figure 2.4. Breakdown of Ministry of Education graduate school places and number of graduate schools by Research Council (1 January 1999).



Source: Ministry of Education decision on funding for four year graduate schools in 1999 (1st September 1998).

disciplines. The academic labour force produced through the system of graduate schools constitutes a core group whose competence and creativity will be essential to the future progress of science and increasingly to industrial competitiveness. The main priorities in postgraduate training are clearly illustrated by the breakdown of student places by discipline (Figure 2.4).

Graduate placement is generally very good. For instance in 1995, only 2.5 per cent of those with a doctorate or licentiate's degree were unemployed one year after graduation. This figure is markedly lower than among those with a master's degree. The situation would seem to be rather similar in other countries: in the Netherlands, six per cent of all PhDs were unemployed, which was less than half the share of those with a master's degree (14%) in 1995. In the United Kingdom, 1.9 per cent of PhDs were unemployed in 1996–1997, markedly less than the figure for masters (4.3 per cent). In France, around 15 per cent of those who earned their doctorate in 1995 were unable to find a job; two years later, the unemployment rate was down to five per cent. In all these countries – Finland, the Netherlands, the United Kingdom and France – postgraduate education has expanded at more or less the same sort of rapid pace during the 1990s.

The graduate school system in Finland has by now shown that it is well capable of producing results, even though there still remain some inevitable flaws and shortcomings. According to a recent report by the Ministry of Education (2000), the directors of graduate schools felt that the new system had made postgraduate training more systematic and more efficient and increased international research co-operation. Students in graduate schools generally regard the standard of education they receive as high. Likewise, a clear majority regard the supervision they receive for their doctoral thesis as good or excellent.

By spring 1999, a total of 889 doctors had graduated from the graduate schools that were launched in 1995. Almost half of them (46%) earned their doctorate in the natural sciences and engineering, almost one-quarter (23%) in the medical sciences and around 15 per cent in both cultural and social science research and in the environmental and natural resources research. Graduate placement was very good: only around 0.3 per cent of those graduating were out of work in 1999. According to the MoE report, the average age at graduation was significantly lower at graduate schools (32 yrs) than prior to the introduction of the new system (37 yrs).

Promoting postdoctoral research careers

One of the most significant science policy decisions of the late 1990s was to start up an extensive postdoctoral researcher system together with other measures aimed at promoting professional careers in research. Out of the FIM 630 million that was allocated from the Government's additional funding programme to the Academy of Finland for 1997–1999, FIM 169.9 million (27%) went towards the postdoctoral researcher system. In addition, funds for the promotion of professional research careers and for setting up the postdoctoral researcher system have been obtained by closing down existing posts for research associate by the year 2000 and by using the resources released to open new posts for postdoctoral researchers and senior fellows. As from 1999, the number of posts for Academy Professors and senior fellows has been substantially increased.

The purpose of the postdoctoral researcher system is to give newly graduated researchers the opportunity to get the qualifications and credentials they need for a professional career in research: the aim is to have around one in five of those graduating take up a professional research career. Posts are available for postgraduate students researching their doctoral thesis, newly graduated doctors and senior researchers who already have shown their research competencies.

The Government's decision to allocate extra funds to scientific research was motivated by concerns of promoting the national economy and social welfare as well as improving the employment situation. This, concretely, has implied increased co-operation between universities and the business sector. In the recruitment of postdoctoral researchers, then, funding has been granted to virtually all applications compiled jointly by universities and business companies. About half of the postdoctoral researchers who received funding through the additional funding programme in 1998 are engaged in business and industry research projects that are run jointly with universities.

The promotion of professional research careers has also meant that researchers with Academy funding have had more university teaching duties than before. In 1997, 20 persons appointed to new posts of senior fellow were also required to take up teaching duties in graduate schools. In 1999, the Board of the Academy of Finland took a decision in principle concerning tenured researchers' teaching duties, according to which the duties of senior research fellows and postdoctoral researchers, as from the beginning of 2000, may include not only research work but also the supervision of theses in their respective field of study as well as related teaching duties.

In 1998, the Academy of Finland awarded FIM 1.5 million to 20 senior fellows in special three-year grants to set up their own research teams. Researchers appointed to research posts have usually received appropriations from the Academy's Research Councils for running their projects. The amounts awarded have varied, but this funding is nonetheless the main foundation for the work of these researchers. In 1999, the Academy's Research Councils made funding decisions worth FIM 33.5 million for researchers appointed to the position of senior research fellow.

Table 2.3. Academy of Finland research posts and appropriations for postdoctoral researchers in 1995–1999 (N)*.

	1995	1996	1997	1998	1999
POSTS					
Academy Professor	23	25	25	29	32
Senior Fellow	99	99	119	152	171
Junior Fellow	137	137	137	88	47
Postdoctoral Researcher	–	–	–	46	111
All posts	259	261	281	315	361
APPROPRIATIONS**					
Appropriations for post-doctoral researchers	–	–	134	224	236
Total of posts and appropriations	259	261	415	539	597

* The number of research posts August 1 each year.

** Appropriations for hiring postdoctoral researchers.

Source: Minutes of the Board of the Academy of Finland, September 27, 1999.

The clearest indicator of the Academy's efforts to encourage professional careers in research is provided by the number of research posts and positions: during the latter half of the 1990s the total number of these positions increased by 131 per cent in 1995–1999 (Table 2.3). During this period the number of Academy Professor posts has increased by 39 per cent, the number of posts for senior research fellow went up by 73 per cent. The number of posts for young PhDs starting their research careers (posts for postdoctoral researchers and senior fellows and appropriations for postdoctoral researchers) has gone up by 188 per cent. The project to develop and encourage professional research careers is continuing with further structural changes: by the year 2004, the number of Academy Professor posts will be increased to 40 and the number of posts for senior research fellows to 250. At the same time, the posts for postdoctoral researchers will be discontinued and replaced by positions for postdoctoral researchers.

Women researchers remain in the minority in the academic community, even though their numbers have been increasing in recent years: in 1998, women accounted for 37 per cent of all tenured staff at universities and the Academy of Finland. The number of women in research has been slowly increasing, but it seems this trend has slowed down during the latter half of the 1990s. In 1998, 46 per cent of our postgraduate student population of around 19,000 were women. The proportion of women among newly graduated doctors has increased from 28 per cent in 1987 to 43 per cent in 1999, but at the same time the number of women in high-ranking research posts in universities and the Academy has shown only slow growth. The proportion of women decreases linearly towards the higher end of the hierarchy of tenured researchers. Although the proportion of women among university professors has steadily increased, the figure for 1998 and 1999 was still no more than 18 per cent. The same imbalance in favour of male applicants is seen where professors are appointed by invitation: in 1998, women accounted for 14 per cent of all university professors appointed by invitation, whereas the corresponding figure for ordinary university appointments was 27 per cent.

The Agreement on Outcome Targets between the Ministry of Education and the Academy of Finland for 1998–2000 said that efforts shall be continued during 1999–2000 to promote the recruitment of women into research careers. The Academy has committed itself to promoting young people's and women's research careers through the postdoctoral researcher system as well as practical measures. In its science policy strategy for 1998–2000, the Academy pointed out that "in the development of research careers special attention needs to be paid to the problems that concern women researchers". The Agreement on Outcome Targets in 1999 between the Academy management and its Research Councils included the following objectives: to increase the number of women in positions of expertise (health research, research in culture and society and the environment and natural resources); to promote equality and to improve women's opportunities in professional research careers; to develop procedures that will facilitate women's recruitment into researcher training in the natural sciences and engineering (natural sciences and engineering research) and to award funding for young scholars and researchers moving between different research units so that people with families can more easily switch between research units (research in the environment and natural resources). At the end of 1999, a proposal for a new equality plan was submitted to the Academy of Finland concerning research staff with Academy funding.

The proportion of women earning their doctorate in Finland has been steadily increasing, and in 1999, 43 per cent of all new PhDs were women. This, as well as the growing number of women seeking a professional career in research, is clearly seen in the decisions taken by the Academy of Finland on applications for research posts. In 1997–1999, the proportion of women among those appointed to the posts of junior fellow and postdoctoral researcher was higher than their share among the applicants for these posts. In the Research Council for the Natural Sciences and Engineering, where women have been in the clear minority among tenured researchers, the proportion of women appointed to research posts has also been somewhat higher than their proportion among the applicants (see Table 2.4).

As for the Academy's research posts, women have again been closing the gap of gender inequality, although the situation is not the same in all Research Councils (Table 2.4). In August 1999, women occupied 37 per cent of all Academy research posts. There were equal numbers of women and men in research on culture and society (50%), and women were also making good headway in health research (42%) as well as in research on the environment and natural resources (41%). In the natural sciences and engineering, the proportion of women (14%) is still considerably lower than in the other Research Councils. In 1998–1999, the proportion of women receiving appropriations for postdoctoral researchers (42%) was slightly below the total share of women applicants (45%). Women are still in the clear minority at the higher end of the research hierarchy, i.e. in posts of senior research fellow and Academy Professor. In 1999, women accounted for less than one-third (31%) of all posts in these two categories. The situation is much better at the other, earlier end of the research career: roughly half of all postdoctoral researchers were women (48%).

Table 2.4. Applicants and appointments to Academy research posts by gender and by Research Council 1997–1999.

Research Council	Senior Fellows						Postdoctoral Researchers/Junior Fellows					
	Applicants			Appointed			Applicants			Appointed		
	Women	Men	Number	Women	Men	Number	Women	Men	Number	Women	Men	Number
KY	25%	75%	446	40%	60%	58	46%	54%	490	49%	51%	52
LT	15%	85%	313	16%	84%	38	25%	75%	287	27%	73%	42
TT	34%	66%	181	36%	64%	25	54%	46%	214	53%	47%	35
YL	29%	71%	242	36%	64%	28	47%	53%	271	52%	48%	30
Total	25%	75%	1,182	32%	68%	149	41%	59%	1,262	45%	55%	159

Research Councils: KY Research Council for Culture and Society
LT Research Council for Natural Sciences and Engineering
TT Research Council for Health
YL Research Council for Environment and Natural Resources

Source: Tutti Research Database of the Academy of Finland.

The Academy's Board and Research Councils have had better success than universities in terms of promoting women's research careers, especially at the top end of the professional career ladder. In 1998, only 18.4 per cent of all university professors – the most likely candidates for the position of Academy Professor – were women, while 31 per cent of all Academy Professors were women (Table 2.5). It is important to stress, though, that the proportion of women occupying university professorships in Finland is higher than in any other EC country. In 1999, the proportion of women occupying Academy senior fellow posts (31%) was almost exactly the same as the corresponding proportion among senior assistants at universities one year previously (30.5%).

Table 2.5. Gender breakdown of Academy post-holders by Research Council (1 September 1999).

Research Council	Academy Professors			Senior Fellows			Postdoctoral Researchers			Total		
	Total	Women	Women %	Total	Women	Women %	Total	Women	Women %	Total	Women	Women %
KY	10	4	40	56	24	43	38	24	63	104	52	50
LT	9	0	0	48	7	15	26	5	19	83	12	14
TT	7	4	57	39	12	31	32	16	50	78	32	41
YL	6	2	33	35	12	34	22	12	55	63	26	41
Total	32	10	31	178	55	31	118	57	48	328	122	37

Research Councils: KY Research Council for Culture and Society
LT Research Council for Natural Sciences and Engineering
TT Research Council for Health
YL Research Council for Environment and Natural Resources

Source: Tutti Research Database of the Academy of Finland, September 1, 1999.

2.2 Funding for technology research

Most of the additional funds made available to scientific research through the Government's funding programme are earmarked for allocation to basic research and technological development through the Academy of Finland and the National Technology Agency Tekes. Tekes' share of government research funding has increased from 28.3 per cent in 1995 to 32 per cent in 1999; the figures for the Academy have risen from 8.3 per cent to 12 per cent, respectively. Conservative estimates put the amount of public money invested in technical R&D in 1999 at around FIM 3.4 billion. This was about 45 per cent of all public research funding.

2.2.1 Research funding from the National Technology Agency

Tekes has a key role to play in creating the necessary infrastructure and other conditions for successful innovation in Finland. One-third of all government R&D grants are allocated through the Agency to business companies, universities and research institutes, which use the money for purposes of technology research and product development. Technology funding through Tekes has increased from FIM 1.6 billion in 1995 to over FIM 2.4 billion (EUR 403 million) in 2000, or by 56 per cent. During this period, Tekes research funding directly allocated to universities and research institutes has increased from FIM 332 million to FIM 738 million. Tekes monies to universities and research institutes are also channelled through companies' product development projects (Table 2.6; see also Chapter 2.3.1).

■ Table 2.6. National Technology Agency funding to universities and research institutes 1995–1999 (EUR 1 = approx. FIM 6).

Year	Direct funding (FIM million)		Direct funding and funding through business enterprises (FIM million)
	Universities	Universities and Govt. Research Institutes	Universities and Govt. Research Institutes
1995	197	332	449
1996	234	388	509
1997	398	612	741
1998	477	705	856
1999	467	738	926

Source: Annual Reviews of the National Technology Agency 1995–1999.

R&D funding through Tekes goes predominantly to supporting technology programmes, which have proved to be a very good way of promoting collaboration and networking between the private business sector and the research community. The Agency's own view is that these programmes strengthen technologies and fields of research that are most crucial to the future of Finland. Tekes funding through the 60 programmes running in 1995 totalled around FIM 400 million. In 1999, Tekes allocated some FIM 1.1 billion to technology programmes. There were a total of 65 technology programmes, involving more than 2,400 business companies and some 860 research units. The Agency was also involved in several major programmes together with other funding bodies, including the Academy of Finland and several ministries.

Small and medium-sized enterprises (SMEs) have received an increasing proportion of Tekes product development funding in 1995–1999. In 1999, grants worth FIM 944 million were awarded to companies with a staff of less than 500, representing 64 per cent of Tekes' total funding for product development. If indirect funding through projects involving major companies is included, the figure increases to 70 per cent. In 1999, Tekes provided funding to 1,376 projects in 1,070 companies. When funding decisions made in previous years are included in the statistics, a total of 2,060 companies in 1999 had product development projects partially funded by Tekes. In 1998, Tekes had over 2,000 business customers. In the same year the total number of companies with R&D operations in Finland was 2,193 (total number of companies 219,273, number of companies with at least 10 employees 7,779). Over one-third of all business customers in 1999 were new clients for Tekes. These companies received over 14 per cent of all product development funding from Tekes.

Tekes has estimated that over the next five years, each million invested in 1998 will produce 6–7 new jobs, FIM 20–40 million in turnover and FIM 10–30 million in exports (this estimate by Tekes experts is based on the companies' own views). Furthermore, the programmes have an even greater impact on employment and welfare by strengthening the national industrial base, which in turn provides a solid foundation for the growth of service industries.

In 1997, public funding for R&D in the business sector accounted for 4.1 per cent of total investment; the average for all OECD countries was 10.2 per cent. In spite of the increase in public technology funding, Tekes funding in 1998 (including loans) represented less than seven per cent of the R&D input by business companies. Public R&D funding in Finland remains well below the OECD average.

In 1998, the private sector invested a total of FIM 13.4 billion in R&D. The electronics and electrical industry accounted for over half of this. During the 1990s, the increase in R&D expenditure by the business sector is almost entirely attributable to the electronics industry. In 1998, R&D expenditure in the electronics industry, in real terms, was almost four times higher than in 1991. In 1995, the industry accounted for 43 per cent of total industrial R&D expenditure. If the industry's own estimates for the increase in R&D expenditure for 1999 were accurate, its share of total R&D expenditure in the private sector will increase to 55 per cent. According to Nokia, its R&D investments in 1998 amounted to FIM 6.8 billion.

2.2.2 Academy of Finland funding for the natural sciences and engineering

The Government's additional funding programme for 1995–1999 resulted in a doubling of research funding through the Academy of Finland. The total value of funding decisions made by the Academy in 1995 was FIM 489 million, in 1999 the figure was FIM 988 million (EUR 166 million). The figures for engineering research in 1995 and 1999 were FIM 75 million and FIM 180 million, respectively (Table 2.7). During the same period, funds allocated to the natural sciences increased from FIM 163 million to FIM 366 million. Academy funding to the natural sciences is allocated through three different Research Councils.

Table 2.7. Academy funding for research in the natural sciences and engineering (EUR 1 = approx. FIM 6).

Year	Total funding FIM million	Engineering FIM million	Engineering %	Natural Sciences* FIM million	Natural Sciences %
1995	489	75	15.4	163	33.4
1996	503	82	16.3	197	39.1
1997	794	111	13.9	319	40.2
1998	836	121	14.5	331	39.6
1999	988	180	18.2	366	37.0

* Channelled through three of the Academy's research councils.

Source: Annual Reports of the Academy of Finland 1995–1999.

The Academy of Finland and Tekes have been working more closely with each other in recent years, increasing their co-operation both in the preparation of research and technology programmes and in conducting joint interim assessments. There are also some research projects that have been jointly funded and evaluated. Researcher training has also been integrated into Tekes technology programmes.

2.2.3 Technical Research Centre of Finland

The Technical Research Centre VTT bases its operation on the strategy set out by the Ministry of Trade and Industry and the development targets identified by the Science and Technology Policy Council. The aim of the R&D efforts at VTT is to improve the technological competitiveness of Finnish industry in the short and long term, to foster the creation of new business based on new technical innovations and to promote employment and production.

Technology and research programmes play a major role in VTT's strategic research. In 1999, VTT was running 16 research programmes. In the same year VTT was involved in 68 longer-term programmes, of which 55 were funded by Tekes and 13 by the Academy of Finland and various ministries. Involvement in Tekes programmes has increased considerably.

VTT is actively involved in Tekes' technology clinics. The purpose of these clinics is to make the knowledge and know-how accumulated in research institutes and universities more readily accessible to SMEs. Indeed, the system has proved to be quite a flexible way of tackling current problems experienced by SMEs.

In 1999, VTT's total funding amounted to FIM 1,088 million (EUR 183 million), of which 30 per cent or FIM 321 million came from budget sources. Compared to VTT's funding for 1995 (FIM 857 million), the figure for 1999 was up by 27 per cent. There has been a moderate increase (9%) in the share of core funding during the period under review, from FIM 295 million[2] in 1995 to FIM 321 million in 1999. During the period from 1995

2 In 1995, VTT received FIM 39 million for capital expenditure on construction, which is not included here in the figures for direct budgetary funding.

to 1998, the share of external funding has increased from FIM 562 million (36%) to FIM 767 million, or 70 per cent of the total figure. Statistics are not available on the share of basic engineering research.

2.2.4 Universities and faculties of technology

According to the Ministry of Education's KOTA database, engineering research is done at the Helsinki University of Technology, the Tampere University of Technology, the Lappeenranta University of Technology, the University of Oulu and Åbo Akademi University. Some work is also done at the University of Vaasa. In 1998, the total costs of engineering research at these universities were FIM 1,087 million, of which funding from budget sources accounted for FIM 470 million. Extramural funding represented 57 per cent of research expenditure. Most of the extramural funding comes from Tekes.

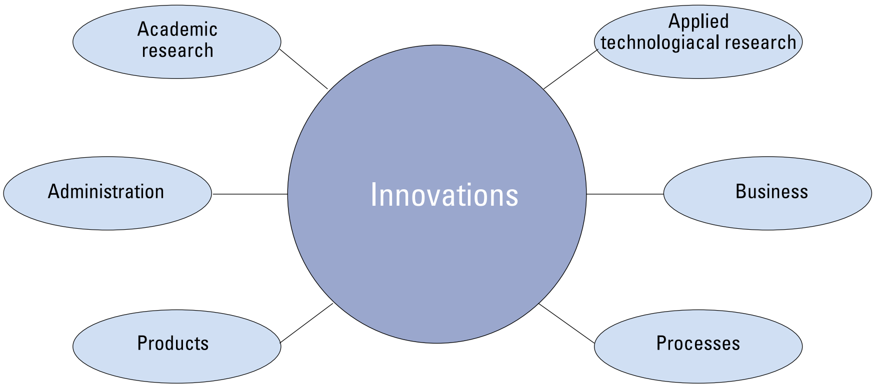
Extra resources have been channelled into researcher training through an additional investment programme aimed at IT industry. Out of the 1,282 postgraduate student places funded by the Ministry of Education, almost half or 591 are allocated to the natural sciences and engineering as from the beginning of 1999. Sixty new places were made available in fields of study that support IT industry: the total number of postgraduate student places supported by the Ministry of Education now is 248.

2.3 Developing the innovation system by means of research co-operation

The changing structures of information and knowledge production. One of the key ways in which scientific research can strengthen its impact in society is to work more closely with other sectors in society. The distinction that is made in R&D operations between basic and applied research and product development work is based primarily on institutional differentiation: most of the basic research is done at universities, while applied work is usually concentrated in universities of technology, research institutes and industry. It is increasingly difficult nowadays to make this distinction between basic and applied research in individual research projects or in consortia involving several projects. Many of these projects now involve both types of work.

Many science researchers have argued that the distinctions between different types of research are becoming blurred with the ongoing changes in traditional institutional structures. The production of new information is characterised by the proximity of the context for which the applications are intended, the involvement of multiple, networked actors in information production, non-hierarchic organisation, a multidisciplinary approach and the transfer of information production outside the traditional scientific institutions (universities). This is not to say that all the factors that have traditionally been important to the science system (such as creativity and the respect for special expertise) have lost their significance. The main engine driving forward the ongoing changes in the science system is the aim of making good, extensive and immediate use of new information, which is typical of all countries that are known as information societies, where information is considered a critical production factor.

■ Figure 2.5. Key innovation factors.



The role of knowledge and co-operation in the production of innovations. The prospects of promoting the competitiveness of the national economy and welfare in society by means of science policy depend most particularly on the quality of production factors as well as on the collaboration received from adjacent, supporting fields of production. The national information society strategy has aimed at promoting knowledge and know-how as key factors of national competitiveness. This has required a commitment to a high quality of production and products instead of working in areas of low added value. A condition for high-quality production, then, is a sufficient degree of national innovation, which is promoted among other things by high-quality scientific research and close relations of co-operation with key innovation actors.

Figure 2.5 outlines the key factors in the innovation process: these are the sources of information that lead to the development of new innovations. In contrast to the innovation chain concept according to which innovations unfold in a process that starts from basic research and runs through applied research to product development and marketing, the network model that is based on the concept of innovation system has it that the information and knowledge required by innovation lies simultaneously in different parts of the network. In particular, it emphasises the role of end-users in the development of innovations. Innovation draws not only on documented scientific and technological knowledge, but also on the so-called tacit knowledge that is always possessed by different actors in the system.

2.3.1 Developing co-operation between universities and the business sector

According to the MoE five-year Development Plan for Education and Research in 1995–2000, the key criteria for the development of research should include high quality, autonomy, high ethical standards and a balance between basic and applied research. Also, new innovations can only grow up out of an efficient innovation system with a balanced system of resource allocation, which is thus crucial to a favourable development of employment and the national economy. A good, efficient innovation system also needs to show a good cost–quality ratio. The education and research strategy for 2000–2004 concentrates largely on the implementation of factors that are of key importance to the development of the information society. According to the strategy universities and business companies should work more closely with one another in identifying research needs and in conducting joint R&D projects.

Hellström and Jacob (1999) describe Scandinavian science and innovation systems as centrally governed, as opposed to systems constructed around dynamic research networks. The Finnish model of science administration shares the same strengths and weaknesses as the Scandinavian model. Networks can only be built insofar as the actors involved have the same sort of interests. It is not possible for any individual actor within a network to dictate the course it will take; this is a key characteristic that distinguishes the network model from traditional hierarchic organisation. The building of network co-operation in the science and innovation system is based on the model of new knowledge production outlined above.

Co-operation between universities and the business sector have been funded through fee-based services, R&D projects financed by companies as well as through various jointly funded projects (in line with the Tekes model, for example). In 1995, revenues from fee-based services were to be used not only to finance the operation of universities themselves, but also to promote exchange of information between business companies and other sectors of society and to provide the necessary supplementary education. The fee-based services provided by universities promote both the production of new information and the dissemination of knowledge and know-how to other sectors in society. The Government's additional funding programme for research has meant that universities are now under increasing pressure to deliver results in terms of research impact. This applies particularly to research carried out with funding from budget sources.

During the period from 1995 to 1999, the value of fee-based services of universities has increased from FIM 600 million to FIM 821 million, showing a nominal increase of 37 per cent. Tekes funding for projects involving universities increased by 140 per cent, or to around FIM 470 million by 1999 (see Table 2.6). Total funding for projects involving business companies and either a university or research institute increased to almost FIM 860 million. Research funding received by universities from the business sector increased from 1995 to 1998 by 33 per cent to FIM 216 million. The increase in the volume of funding clearly lends support to the conclusion that universities and business companies have had increased co-operation in recent years. The most important factor in facilitating this co-operation has been the funding provided through Tekes.

It is a common criticism that universities do not pay enough attention in their collaboration with industry to the specific interests of the private business sector. However, OECD surveys of national innovation systems have found that innovation may also be undermined by inadequate investment in maintaining the quality of basic research. Industry has for its part stressed the importance of the creative research that is done in universities as well as their high standards of know-how, which are seen as key preconditions for business success on the globalised markets. It is also acknowledged that industry itself does not necessarily always appreciate the role of basic research in guaranteeing knowledge reproduction. On the other hand, industry has also highlighted certain problems related to the institutions that maintain basic research: for instance, the management and administrative culture of universities, incentive systems as well as the old fears that researchers will lose their scientific independence if they work closely with business and industry.

For the time being it is impossible to say exactly how much or how far industry is prepared to invest in scientific collaboration that is in line with its own goals and objectives but that has no immediate economic benefits. Since R&D is highly labour-intensive, wage and salary expenses and other inputs may be regarded as a useful measure of the commitment of different parties in networks. For instance, in connection with the additional training programme aimed at the information industry 23 companies joined forces with universities to conduct a survey on the new equipment required. On the basis of the surveys, the companies decided to donate a total of FIM 47 million to the Helsinki University of Technology, the Tampere University of Technology and the University of Oulu for purposes of acquiring and upgrading their research equipment in 1999–2001. Through the programme, public funding allocated to universities for the corresponding period amounted to around FIM 300 million, which is intended for training purposes.

2.3.2 Government research institutes

Government research institutes are responsible for conducting sectoral research. They are also expected to produce high-quality scientific research, to do customer-oriented and problem-centred applied research and to bring research results into the practical domain. Government research institutes also have various official administrative duties. Ministries bear the main responsibility for developing sectoral research in their respective administrative branches.

Overall responsibility for the development of sectoral research rests with the Science and Technology Policy Council. It was on the Council's recommendation that all government research institutes were evaluated by the end of 1999. During 1995–1999, the first recommendations ensuing from these evaluations were put into effect. The institutes are monitored and evaluated as part of a broader economic and operational planning and development scheme by applying the principles of management by results.

The Science and Technology Policy Council has considered the organisation of sectoral research institutes from the vantage-point of collaboration and set specific targets for it. The task of funding bodies is to further strengthen horizontal co-operation. Instead of simply analysing the internal development of individual institutes or sectoral research, it is considered important to look broadly at the whole R&D system. Ministries are expected to develop the funding structure of sectoral research in such a way that their uncommitted research funds will increase in relation to the institutes' funding or otherwise committed appropriations. In addition, the volume and share of external funding for government research institutes shall be increased in a manner that makes the best possible sense with respect to fulfilling their basic functions.

Government research institutes both allocate public R&D funding and carry out research with this funding. During 1995–1999, the share of public research funding allocated to government research institutes dropped from around 21 per cent to 16 per

Table 2.8. External funding for research institutes in 1995 and 1997 (EUR 1 = approx. FIM 6).

Government Research Institute	External funding FIM 1,000		Real change in external funding
	1995	1997	1995–1997
Veterinary Medicine and Food Standards Research Institute	2,241	2,110	–8%
Finnish Geodetic Institute	1,949	2,668	34%
Geological Survey of Finland	1,852	3,575	89%
Finnish Meteorological Institute	16,561	15,779	–7%
National Public Health Institute	38,000	66,000	70%
Research Institute for the Languages of Finland	229	434	85%
Agricultural Economics Research Institute	3,000	4,315	41%
Agricultural Research Centre of Finland	32,100	52,000	58%
Finnish Institute of Marine Research	2,700	5,100	85%
Finnish Forest Research Institute	45,503	40,210	–14%
National Research Institute of Legal Policy	791	1,244	54%
Finnish Game and Fisheries Research Institute	15,789	14,507	–10%
National Research and Development Centre for Welfare and Health	5,617	14,500	152%
Finnish Environment Institute	29,000	53,000	79%
Radiation and Nuclear Safety Authority	3,443	8,060	129%
Finnish Institute of Occupational Health	22,200	26,400	16%
Government Institute for Economic Research	1,550	2,231	41%
Technical Research Centre of Finland	544,933	667,480	20%

Source: Statistics Finland and the Academy of Finland's enquiry to government research institutes in 2000.

cent. In real terms, basic funding earmarked for government research institutes in the state budget has declined in 1993–1999, especially in relation to external funding.

Success in securing selective competitive funding may be regarded as an indicator of a high standard of scientific research. In many cases government research institutes have consciously and systematically sought to increase their external funding, and indeed most of them have seen the volume and proportion of external funding rise during the latter half of the 1990s (Table 2.8). In many cases this is explained by the rapid increase in EU funding. At the same time government research institutes have also received more and more of the uncommitted appropriations that are granted by ministries. For instance, the non-earmarked research funds awarded by the Ministry of Forestry and Agriculture constitute a significant part of the external funding received by research institutes under its jurisdiction. Most of the external funding for research institutes working in the social sciences comes from Ministry sources.

Funding granted by the Academy of Finland to research institutes has increased from FIM 27 million in 1995 (5% of total research funding) to FIM 61 million in 1998 (7%). In 1995, funding was awarded to 15 research institutes, in 1998 to 18. In 1998, the National Public Health Institute received almost half of all the funds, primarily through research programmes. In the latter half of the 1990s most of the funding has gone to the

National Public Health Institute, the Meteorological Institute, VTT, the Agricultural Research Centre and the Forest Research Institute.

While funding awarded by Tekes to universities and research institutes increased from FIM 332 million in 1995 to FIM 705 million in 1998, the share received by research institutes has declined in the latter half of the 1990s from 41 to 32 per cent (i.e. from FIM 135 million in 1995 to FIM 228 million in 1998). In 1995–1997, VTT has received 86–88 per cent of these funds. In 1998, the share received by other research institutes increased to 20 per cent. Other major funding recipients during the latter half of the 1990s have included the Meteorological Institute, the Institute of Occupational Health and the Geodetic Institute. In particular, the Institute of Occupational Health has seen a very rapid increase in funding received through Tekes.

Roughly half of all research institutes get private funding from outside sources. Institutes with a high volume of research funded by business and industry include VTT, the Agricultural Research Centre and the Institute of Occupational health. Most of the outside funding from international sources comes through EU sources. Research institutes have now become somewhat more selective in choosing which EU research programmes to join: the decision is weighed first and foremost against the institute's own strategy. On average research institutes have been quite successful with their applications for EU funding. In the Second Framework programme Finnish research institutes were involved in a total of 36 projects; the figures for the Third and Fourth Framework programmes were 212 and 539 projects, respectively. In the Fourth Framework programme the most successful participant was VTT, which was involved in 300 different projects. The Institute of Occupational Health, the Meteorological Institute, the Agricultural Research Centre, the National Public Health Institute and the Radiation and Nuclear Safety Authority were involved in over 20 projects each. The Government Institute for Economic Research and the Consumer Research Centre (which are smaller research institutes concerned with social issues) were involved in a few projects. Finnish participation in EU Framework programmes was most common in the environmental programme (ENV 2).

2.3.3 Role of national cluster programmes in the Finnish science and innovation system

Finnish cluster policy is grounded in the national industry strategy that was published in 1993 by the Ministry of Trade and Industry. This strategy includes an analysis by the Research Institute of the Finnish Economy (ETLA) of the country's industrial clusters, their state and development prospects. Cluster thinking is based on the theory of improving national competitiveness by way of strengthening industrial clusters. A distinction can be made between four factors of competitiveness; production factors, corporate strategies and competitive environment, demand factors and collaboration with adjacent and supportive fields.

In line with the national strategy of knowledge and know-how, R&D funding is expected to improve the quality and impact of the innovation system. To help meet these objectives, the Government's additional funding programme has allocated budget resources for the development of seven different clusters. Cluster programmes are designed to create networked know-how clusters that generate new innovation potential, improve competitiveness, and create new jobs and business in different industry and service sectors. As well as increasing the number of innovations, cluster development can also speed up the production of new innovations. The clusters proper are the forest, foodstuffs and environment cluster, the transport and data communications cluster, the National Workplace Development Programme and the welfare cluster. Some clusters are further divided into smaller programmes.

It is impossible to put any single figure on the total amount of funding allocated to cluster programmes because they can be defined in so many different ways. If the volume of cluster programmes is estimated on the basis of the appropriations allocated by ministries and other public funding bodies, the final sum for 1997–1999 is over FIM 600 million. If all contributions to cluster projects plus the estimated inputs of the research organisations themselves are included, the figure is much higher at around FIM 1.3 billion. These estimates are based on funds budgeted to cluster programmes. By far the biggest research cluster is the welfare cluster, with a volume of around FIM 800 million. Other major programmes include the forest cluster research programme and the environment cluster research programme, in which investments amount to close on FIM 300 million. The general objectives of the national National Workplace Development Programme were in line with those set out for the cluster programme. Total funding for this programme adds up to FIM 200 million, but we have here included no more than FIM 30 million that have been spent in network projects. The bulk of funding for cluster programmes comes from two administrative branches, viz. the Ministry of Social Affairs and Health (Well-being cluster) and the Ministry of Trade and Industry (Transport cluster), which provides funding for several programmes through Tekes.

It is still too early to assess the outcomes and the impacts of cluster programmes in terms of how they have succeeded in generating new jobs and new business. What can be assessed even at this early stage of the projects is the work that has gone into building the networks of co-operation, which is a key precondition for the development of the innovation system otherwise. In this light the results are quite encouraging. There is increased interaction and collaboration among different administrative branches, funding bodies and the various research organisations. For example, the research programme in the environment cluster has been jointly funded by the Ministry of the Environment, the Ministry of Trade and Industry, Tekes and the Academy of Finland (see Table 2.9) as well as by the private sector. Research and development projects involve people and units from different universities, research institutes and companies. There is similar co-operation in most cluster programmes.

Indeed, collaboration and interaction is the main strength and asset of all cluster programmes. At the same time it is recognised that the different parties involved in the projects must retain their own independent profiles: it is this diversity that creates the synergy benefits in the first place. Although co-operation through clusters does have some convergence effect with regard to the interests of the different parties, clusters can only retain their innovation potential through diversity. The high quality standards applied in the selection of projects are also crucial in terms of producing high-quality results. Funding from Tekes seeks to promote practical objectives and applications and co-operation with business companies.

■ Table 2.9. Academy of Finland involvement in cluster programmes (EUR 1 = approx. FIM 6).

Cluster programme	Total funding FIM million	Academy of Finland	
		Research programme/ Targeted programme	Funding granted FIM million
Wood Wisdom[1]	200	Material Science of Forest-based Products	28
Food Products Cluster	28	–	–
Well-Being Cluster	800	Research Programme on Ageing	15
Transport Cluster (Tetra Programme)[2] (Ketju Programme)	70 85	– –	
Telecommunications Cluster (NetMate Development Programme)	45	–	–
Workplace Development Programme	30	–	–
Environmental Cluster	80	Management of Materials Flows and Recycling of Materials	6

1. Finnish Forest Cluster Research Programme.

2. Finnish national R&D programme on transport telematics infrastructure.

Source: Co-ordinators of the Cluster Programmes and Research Database of the Academy of Finland.

Cluster programmes seem to vary to some extent in terms of how well different kinds of knowledge interests are interwoven within them. Some of them are pure basic research projects, others also involve applied research and development work. Most typically, the programmes are expected to generate new knowledge and know-how[3]: this is the case in over 75 per cent of the projects. Expectations of practical benefits are much less common. No more than one in five projects are expected to produce increased turnover or the innovation of a new public service. Expectations related to patenting or licences are rarer still. Most projects are in one way or another about the application of existing knowledge or theories, only one-quarter indicate that the aim is to produce an entirely new type of know-how. In view of the goals of cluster programmes – competitiveness, new products or services – it would seem then that the projects have exactly the right orientation. However, it seems the distance from applied research to practical innovations is still quite long.

The funding bodies and their science and technology policy priorities have to some extent influenced the profiles of cluster programmes. For instance, projects funded by the Academy of Finland are multidisciplinary efforts aimed at producing entirely new kinds of knowledge and know-how far more often than projects funded by Tekes, for instance. The key thing is that projects funded by both the Academy and Tekes have a diverse range of goals and objectives. This in itself indicates that cluster programmes have the potential to locate interfaces that can lead to the kind of know-how that is needed in producing new innovations.

3 Based on preliminary data on cluster programme projects compiled by the Finnish National Fund for Research and Development Sitra.

3 University structures, steering mechanisms and strategies

3.1 Long-term development

Since the 1980s, the general climate in Finland has been very much pro education and pro research. In particular, there has been a strong commitment to strengthening the position of research and postgraduate training in universities. In the early 1980s research funding was still comparatively modest, but in 1981–1985 financing showed faster growth than in the other OECD countries. This was possible primarily because the Science and Technology Policy Council and the Government were unanimous in their views that funding for the institutions that were responsible for producing and disseminating new knowledge should be raised to the same level it had already reached in countries that were seen as Finland's main rivals. As a consequence, universities' R&D expenditure doubled in real terms and research funding as a proportion of GDP increased to close on two per cent.

During the 1980s, funding for the science system continued to develop favourably, as did the structures and infrastructure of the university system as a whole: budget funding for universities and the resources made available to government research institutes continued to grow steadily. At the same time the position and the preconditions for research and postgraduate training were further strengthened. Legislation issued in 1986 for the development of higher education and the related decision by the Council of State (the so-called resource paragraph) guaranteed that universities would see a steady increase in research appropriations until at least 1991. However, this favourable trend came to an abrupt end with the onset of economic recession in the early 1990s. R&D expenditure in universities still showed some growth in the early 1990s, but in real terms expenditure then started to decline.

In 1996, the Finnish Government took the decision significantly to increase its spending on research by 1999. This decision was closely in line with its earlier policy decisions concerning the information society as well as the knowledge and know-how strategy: it was recognised (as has been in a number of other countries as well) that science and technology policy was closely linked with favourable economic and employment trends and therefore was a useful way of cutting loose from the recession. The first concrete steps to develop the national innovation system were taken with the decision to raise significantly the volume of Government funding of R&D (see Chapters 1 and 2). Public funding for R&D started to grow faster than ever before. At the same time there were increasing calls on the part of funding bodies for greater socio-economic relevance in research.

The question of how research impacts social development and economic success in particular has attracted growing public interest in Western industrial countries ever since the 1960s, and most notably so in the 1990s. The importance of research and developing the science system has of course long been recognised in Finland, but it is only quite recently that the country has been portrayed as a major international force in research and development around high technology. This emerges clearly when we look at the recent trends of research intensity and high technology exports from Finland. In latter half of the 1990s the national strategic significance of research as a whole has clearly increased. Compared with the other OECD countries, Finland has worked consistently and systematically to invest in the further development of education, know-how, research and technology. A recent OECD report published in 1998 on the associations of science and technology with production and employment identifies a number of strengths in the Finnish system: these include the administration of the scientific base, the economic resources invested in research, co-operation between universities and the business sector and the development and application of technology.

3.2 Change and transformation

The Finnish university and science system has been in a more or less continuous state of flux since the late 1930s. As early as 1938 when so-called Old Academy of Finland was founded, there were plans to develop and upgrade researcher training, to revise the system of resource allocation with a view to increasing the efficiency of research and to allocate the bulk of funds to the most efficient researchers. From this point of view the pressures under which universities find themselves today should be nothing new to them. University research has been influenced by factors both internal and external to the science system. Although the accent in the debate on the relationship of universities to society has tended to shift and fluctuate somewhat over time, some of the themes and issues have always been the same. These include the emphasis on the social significance of science and research, the importance of R&D to industry and the aim of using research and technology to resolve social problems and to promote welfare.

One of the issues that reappeared on the agenda in the late 1980s was the importance of universities working closely with government research institutes and business companies. In particular, the aim was to encourage co-operation between basic and applied research as well as development work. At the same time attitudes towards research began to change. Especially in public administration and in the private sector, the key objectives were to promote technological development in industry and to innovate industrial products based on research, i.e. to maintain the strategic capacity of industry for reproduction and for strengthening its competitiveness. There were also increasing calls for university research to show greater efficiency, productivity and impact.

Since the late 1980s and early 1990s, universities have worked consistently to streamline their operation for a clearer division of labour and greater efficiency. Research institutes have been combined into larger and better organised units. By international comparison Finnish universities are comparatively small and they have been encouraged to specialise in fields of study that they know best. The local and regional role and influence of universities has clearly increased. The government has stressed the importance of eliminating unnecessary overlap in the operation of universities. The aim of raising the standard of research to a high scientific level has required a determined and consistent policy of allocating funds to projects that have been selected on a competitive basis.

It is very rarely during their 900-year history that Western universities have had to cope with such a burden of expectation and outside pressure as they are faced with today.

University steering mechanisms, research funding systems and the criteria on which funding is allocated have all been influenced by the internationalisation of education and research, the growing pressure of expectation from outside the university system, the increased duties and responsibilities of universities, changing values and cultures and the decrease in direct budget funding from the government. All these changes are also reflected in the everyday life of universities, and there is ongoing debate – both within universities and on the outside – as to how exactly these changes are affecting universities. As far as the universities themselves are concerned, their most pressing concerns are the priorities of government R&D and the future funding of basic research in universities.

The primary functions of universities include research and education. In addition to the cultural function of education, universities themselves like to stress the key significance of academic autonomy. Free research is still regarded as the main precondition for autonomy. That includes the freedom to choose what one wants to research and the right to publish research results that might be detrimental to whoever is funding the research. The situation is further complicated by stringent quality requirements, by the continuing growth of international co-operation and by ever closer links between the university system and industry. On the other hand, the main concern for decision-makers and end-users of research results is their utility and economic relevance.

3.3 Steering system and structures

Universities in Finland have seen quite similar environmental changes in the late 1990s as universities in other OECD countries. The main operational and structural features of the recent developments in Finland have included the launch of the centre of excellence system, the creation of the graduate school system, the advancement of professional research careers through the postdoctoral researcher system, as well as the increased co-operation between universities and units, disciplines, research institutes and industry. These changes have been conducive to the development of new creative research environments, which in all universities has met with a positive response.

3.3.1 Management by results

A priority concern for many OECD countries in the 1990s has been to increase the efficiency of public administration and in general to facilitate the job of management in the public sector. In Finland these efforts have been chiefly geared to breaking loose from the old centralised planning system and to replacing it with a results-minded and service-oriented management culture. Instead of rules, norms and meticulous control of spending, the accent now is on targets and agreements on the allocation of the resources needed to attain those targets.

The Ministry of Education and universities have regularly negotiated agreements on target outcomes since 1994. The change in the steering philosophy has been fast indeed; in fact according to an estimate published in 1999, it has been among the fastest in the whole of Europe. The principles of management by results and cost-efficiency were established very rapidly in the Finnish academic world with the introduction of development legislation in 1986–1996. In their negotiations on target outcomes, the parties involved agree upon operational targets as well as on basic funding, project funding and performance-based funding. At the same time decisions are made on each university's functions, areas of specialisation and priority areas of research and education. The agreements on target outcomes are drawn up for a period of three years at a time, but they are revised annually in a supplementary protocol on the following year's budget.

The basic functions of universities, scientific research and postgraduate training and basic education are spelled out in the 1998 University Act, which was adopted in place of 20 laws that separately governed each university in the country. The Act guarantees the autonomy of universities as well as the independence of their research and teaching. Increased decision-making powers have indeed been devolved to universities, and the former system of detailed budget steering has been discarded in favour of management by results, which emphasises the links between operative targets and performance-based funding. The Act clearly increased administrative decision-making authority, including the right for universities to decide independently on how they want to arrange their research and education. Ultimately the motive has been to give universities the flexibility they need to respond more rapidly and effectively to changing situations. The new University Act also allows for a new kind of strategic management.

Overall then the purpose is to tie funding more closely to operative targets and results. It has been an issue of some debate as to whether universities really have seen their freedom increase, or whether it has in fact been curtailed. The view of universities themselves is that while they have gained greater independence in terms of financial decision-making, the decision to tie up budget funding with certain projects and degree targets in different fields of study has acted in the opposite direction. Nonetheless one can quite safely argue that universities have seen a quite decisive increase in the freedom and autonomy they enjoy. Control is now exercised through operative targets, with the criteria used in defining and measuring the outcomes of universities assuming key significance.

Core funding for universities is today tied to their performance: universities are expected to produce a certain number of degrees and qualifications and to do good research. Two-thirds or 65 per cent of core funding is allocated on the basis of teaching performance, 35 per cent on the basis of research performance. Performance on the education side is measured by the number of master's degrees, for research the corresponding measure is the number of doctorates earned. During the 1990s a formula was introduced for the determination of university funding; the budget reform will take full effect during the 2001–2003 term of the next agreement on target outcomes. Universities have made critical comments about the amount of basic funding made available relative to the number of degrees they are expected to produce and, second, about the apparent disregard for quality in the model. For universities themselves, the most important consideration is the continuity and stability of basic funding. There has also been some dissatisfaction about the amount of uncommitted basic funding relative to funding earmarked for specific purposes as well as to the share of performance-based funding. Around 2–5 per cent of all resources are allocated on the basis of output. The Ministry of Education has undertaken to develop the university budgeting system so that it will allow universities to fulfil their basic functions, to meet their obligations in the fields of education, research and cultural policy, and to reward high quality and efficiency.

The University of Helsinki is the first university in Finland that has carried out an extensive evaluation of the quality of its research and on this basis proceeded to create a model in which quality ranks on a par with quantity as a criterion for the internal allocation of university resources. Each university faculty has been assigned a numerical rating which describes the quality of its research and which will be used in the allocation of funds among faculties in 2000–2004. In this model the results of the quality reviews are used to help allocate resources to the most successful areas. At the same time, work is continuing to develop a system that will help poorer performers improve the quality of their research.

The University Development Act of 1986 included a decision by the Council of State which required that all universities adopt an evaluation system that produces adequate and comparable data on research and education outputs and their respective costs. However, the issue of research evaluation in universities remains somewhat controversial. For instance, it has proved quite problematic to devise accurate measures and to use indicators of performance or output in the context of scientific research. Nonetheless evaluation is definitely becoming an integral part of the university system.

3.3.2 Objectives of structural development

Finnish universities have seen an ongoing process of structural development throughout the 1990s, which can be traced back to the 1986 Development Act. This Act states that new resources shall be allocated on the strength of results achieved in research and education and that existing resources shall be reallocated according to changing needs. When the government was forced to cut back its research funding in 1993–1996 under the pressures of economic recession, it also had to reconsider the objectives and policy lines of higher education. Cutbacks alone were not enough, but structural changes were also required to increase the efficiency of the science system. The development effort was to be based on the same principles of efficiency, productivity and impact that were adopted through the system of public administration.

The decision to launch a programme of structural development in Finnish universities was taken by the Government in connection with the adoption of new development plans for education and university research in 1993–1996. Both schemes required that universities shall specialise and adjust their education and research operations to the prevailing economic realities. The agreements on target outcomes emphasised (as they still do today) that structural development shall be an ongoing exercise. A key objective in the development of universities is to improve the quality of education and research and to enhance the efficiency and cost-effectiveness of universities.

In the 1990s, Finnish universities have been set the following development targets: 1) the accent in the development of universities shall be on scientific research and a high quality of artistic activity, which lay the foundations for teaching; 2) the necessary conditions shall be guaranteed for high-quality basic research and researcher training; 3) research and education shall be arranged with a view to flexibility and diversity and universities shall focus on their special areas of expertise so that research and education can advance to the top level; 4) research funding shall be increased to new units, to promising new disciplines and to current and important research problems; 5) young post-doctoral researchers shall be offered better opportunities to gain the qualifications they need as professional researchers; 6) joint research projects between universities and the private business sector shall be supported with a view to the regeneration of industrial activity.

The current five-year Development Plan for Education and Research (1999–2004) states that by the year 2002, universities shall allocate at least three per cent of their basic resources (at 1999 level) to improving the conditions for education and research and to strengthening their special fields of expertise.

The aim of the exercise of structural development is to strengthen the university network, to facilitate the allocation of resources to strategic growth areas and to support new emerging disciplines. The purpose is to give universities the tools they need to cope in the situation where their core funding has been reduced and to respond to other changes in their environment. In many universities structural development has been a very far-reaching exercise, aiming ultimately to streamline operations and to eliminate unnecessary overlap that ties down scarce resources. Existing structures have been made more flexible and efficient by closing down and combining units and departments and by setting up new ones where that has been deemed necessary. Nonetheless universities still have a very large number of units, which has been the subject of some controversy.

University structures have shaped the research environments in different disciplines and different fields of study in quite different ways. Interdisciplinary co-operation has increased both in research and in education. Scientific communities are no longer formed strictly within the confines of academic disciplines. In the 1990s, umbrella organisations have been formed around research teams that apply the methods of molecular biology and modern biotechnology to tackle biological and medical problems: examples include Biocentrum Helsinki, Biocenter Oulu, BioCity in Turku and the A. I. Virtanen Institute and the Institute of Applied Biotechnology at the University of Kuopio. Similar working methods have also been adopted by engineering researchers.

Changes have also been made to the traditional structures of university teaching and posts and offices so as to allow for a more efficient response to the current needs and challenges of research. There have been some calls to reform the faculty system, and several universities are indeed now giving serious thought to these suggestions. Bearing in mind the sweeping changes they have seen in their funding structures and in the numbers of graduating students, and not least in the new responsibilities they have been assigned (e.g. adult education in open university), it is fair to say that, overall, universities have succeeded very well in their development efforts. These efforts are continuing to allow universities to meet the productivity targets that have been set for them.

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The main accent in universities' development efforts has been on strengthening their own special areas of expertise: resources have been concentrated on these areas at the same time as less significant branches have been cut back. This is seen most clearly in the natural sciences, engineering and the life sciences, for which one of the most important objectives is to support education and research and to strengthen the knowledge base in rapidly emerging fields of production. Structural development also requires that universities invest in internal quality evaluation and in establishing their own funding criteria.

3.4 Universities' resources at the turn of the millennium

3.4.1 Research expenditure and staff in the 1990s

Total R&D expenditure in Finland has doubled in nominal value from 1991 to 1998. During the same period universities' research expenditure has increased by around 55 per cent. In 1998, the R&D expenditure of the university sector totalled FIM 3.9 billion (Table 3.1), of which central university hospitals accounted for about FIM 430 million. In real terms, universities' research expenditure increased on the previous year by 11 per cent, which was an exceptionally sharp rise compared to earlier on in the 1990s. For instance, universities' research expenditure increased from 1991 to 1995 by a total of no more than seven per cent in real terms. In 1998, universities did a total of 13,653 person-years of research, of which central university hospitals accounted for 863. The increase in the number of research years since 1997 was around 15 per cent.

Table 3.1. R&D expenditure by sector in 1991–1998 (FIM million and %) (EUR 1 = approx. FIM 6).

Year	Enterprises		Public sector*		Universities	University hospitals		Total
	FIM million	%	FIM million	%	FIM million	FIM million	%	FIM million
1991	5,798	57.0	2,126	20.9	2,248	–	22.1	10,172
1995	8,166	63.2	2,226	17.2	2,524	–	19.5	12,916
1997	11,396	66.0	2,430	14.1	3,062	386	20.0	17,274
1998	13,395	67.3	2,639	13.2	3,482	430	19.6	19,946

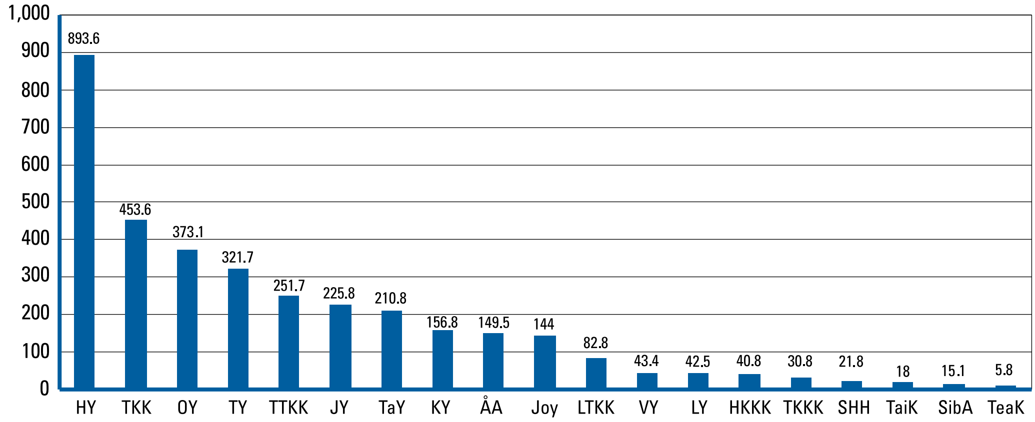
* Including private non-profit operations.

Source: Statistics Finland.

Universities differ quite considerably in size, which is seen in the fact that the combined research expenditure of the four biggest universities in 1998 accounted for almost 60 per cent of the total research expenditure in the university sector (Figure 3.1). Different universities also show quite different patterns in their research expenditure during the 1990s (Figure 3.2). Overall the volume of university research has increased very clearly during the 1990s. These favourable trends have mainly been the result of increased external funding: all universities have had good success in this regard.

In 1998, the highest figure for R&D expenditure in Finnish universities was recorded by the natural sciences (33%), followed by engineering and technology (20%) and the social sciences (20%); the agricultural sciences recorded the lowest share (2%). From 1991 to 1998 the natural sciences increased their share by 11 percentage points. The figures

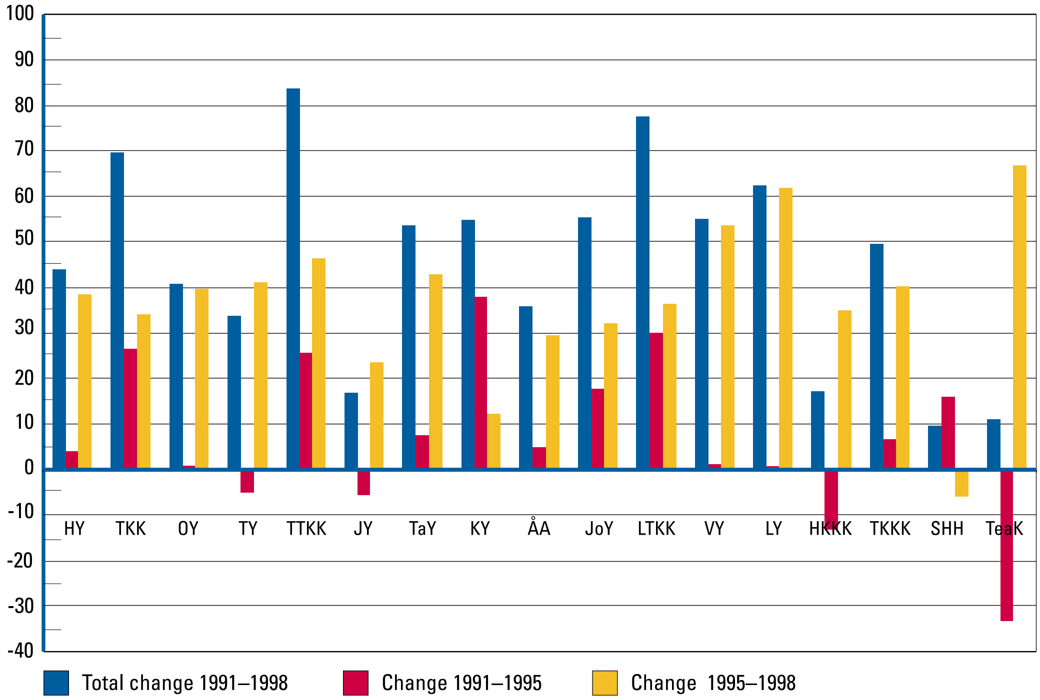
■ Figure 3.1. Research expenditure by university in 1998 (FIM million; EUR 1 = approx. FIM 6).



HY	University of Helsinki
TKK	Helsinki University of Technology
OY	University of Oulu
TY	University of Turku
TTKK	Tampere University of Technology
JY	University of Jyväskylä
TaY	University of Tampere
KY	University of Kuopio
ÅA	Åbo Akademi University
JoY	University of Joensuu
LTKK	Lappeenranta University of Technology
VY	University of Vaasa
LY	University of Lapland
HKKK	Helsinki School of Economics and Business Administration
TKKK	Turku School of Economics and Business Administration
SHH	Swedish School of Economics and Business Administration
TaiK	University of Art and Design Helsinki
SibA	Sibelius Academy
TeaK	Theatre Academy

Source: Statistics Finland.

■ Figure 3.2. Change in universities' research expenditure in 1991–1998 (in real terms, %).



Source: Statistics Finland.

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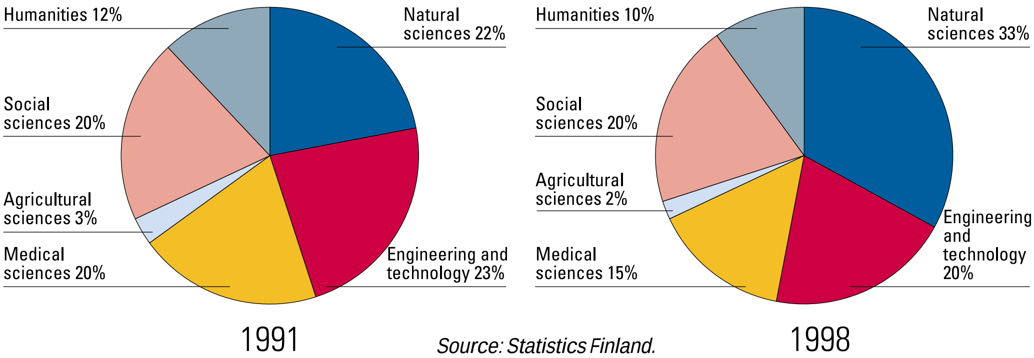
dropped for the medical sciences (by 5 percentage points), engineering and technology (3 percentage points), the humanities (2 percentage points) and the agricultural sciences (1 percentage point). There was no change in the share of the social sciences (Figure 3.3).

Figure 3.3. Universities' research expenditure by field of science in 1991 and 1998 (%).



Source: Statistics Finland.

There have been very significant changes in the structure of teaching and research staff in Finnish universities in the 1990s (Table 3.2). The trends have been quite similar in all universities. The increase in outside funding has meant that staff numbers have grown especially since 1994. In 1999, the number of research personnel working at universities (including staff in graduate schools) was more than three times higher than at the beginning of the 1990s. The number of professorships increased in the early 1990s, but since then the numbers have come down to some extent. Some professorships have been changed so that they are now fixed-term, rotating and invitational: the purpose here has been to allow for greater flexibility in responding to the development needs in new disciplines and fields of research.

The relative increase in the number of posts of senior assistant was greatest in the latter half of the 1980s and in early 1990s. Previously these were the only posts at the so-called intermediate level; now, new posts have been set up for instance for research lecturers. The number of positions for assistants has steadily declined throughout the 1990s, but most notably so towards the end of the decade. The number of full-time teachers has also steadily decreased. The share of women among university teaching staff has slightly increased (Table 3.3). Women are in the majority in two categories, i.e. that of lecturer and full-time teacher.

According to OECD statistics, Finland spent 1.7 per cent of its GDP on higher education[1] in 1997; this was also the average figure for industrial countries. Education expenditure per student in the Finnish university sector was well below the OECD average. In 1997, education expenditure per university student in the OECD countries averaged 8,600 US dollars, in Finland the corresponding figure was 7,145 US dollars. In addition, the number of students per teacher has steadily increased during the 1990s. In 1997, there were 18 students per university teacher in Finland, while the figure in OECD countries was just over 14. The situation in Finland has continued deteriorate: in 1999, there were 21 students per every teacher.

1 Higher education comprises universities, polytechnics and certain institutions.

Table 3.2. Structure of posts and offices in Finnish universities in the 1990s (N).

	1990	1992	1994	1996	1999	Change 1990–1999
Professors	1,842	1,924	1,980	2,070	2,044	11%
Senior Assistants	523	629	614	657	671	28%
Assistants	1,834	1,808	1,805	1,750	1,486	–19%
Lecturers	1,770	1,854	1,853	1,953	1,865	5%
Fulltime teachers	585	523	401	348	298	–49%
Research staff	1,890	2,262	2,630	4,212	5,998 *	217%
Other	11,284	11,508	12,045	13,072	13,802	22%
Total	19,728	20,508	21,328	24,062	26,164	33%

* Including those working in graduate schools.

Source: KOTA Database of the Ministry of Education.

Table 3.3. Gender breakdown of university teaching staff in 1990 and 1999.

	1990		1999	
	Women %	Men %	Women %	Men %
Professors	13	87	18	82
Senior Assistants	26	74	33	67
Assistants	36	64	45	55
Lecturers	44	56	54	46
Fulltime teachers	52	48	60	40
Total	32	68	38	62

Source: KOTA Database of the Ministry of Education.

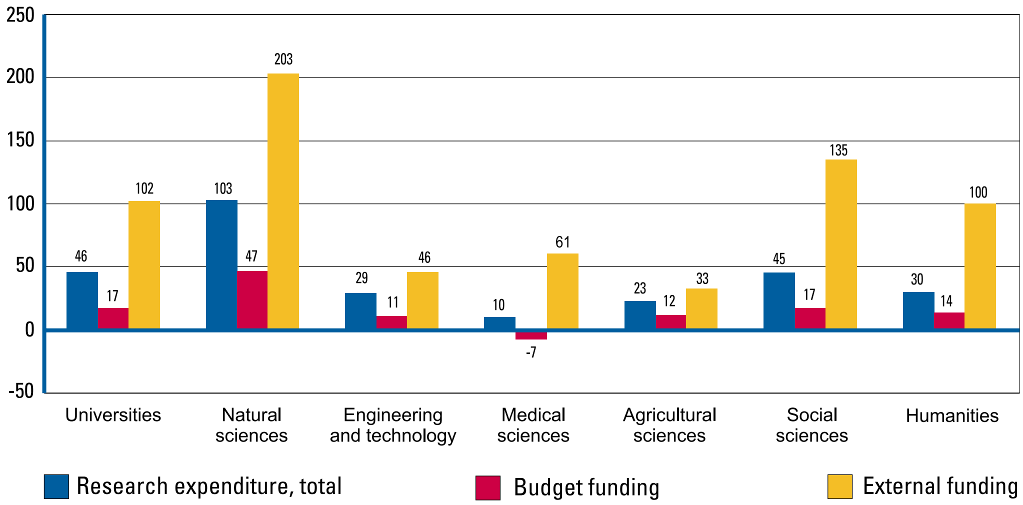
3.4.2 External research funding

Universities have two main sources of funding: part of their funds come from budget sources, part of them come from external sources. In recent years, the share of external research funding has rapidly increased, and it is a widely shared view in universities that this has had a growing impact on the orientation and emphasis of their research. Most notably, universities have seen a strengthening of project research in which they have their own vested interest. Responsibility for the supervision of research that is funded from outside sources lies with the management of universities. External funding should support the objectives agreed upon by the Ministry of Education and universities in their negotiations on target outcomes. In the future universities are expected to show a stronger action strategy that also takes into account the use and allocation of external research funding.

Universities have had good success in securing research funding from outside sources, which has indeed been more and more readily available both at home and abroad. However, universities maintain the position that the sharp increase in external funding is no substitute for basic funding as regards the fulfilment of their primary functions.

From 1991 to 1998 universities' research expenditure increased in real terms by 46 per cent (Figure 3.4). The biggest change has occurred in the natural sciences, the smallest in the medical sciences. The trends for universities' research spending from budget sources have been very moderate with the exception of the natural sciences, where core funding has increased by 47 per cent. The increase in extramural funding from 1991 to 1998 amounted to 102 per cent. The increase in external funding has meant that the total volume of university research has not declined in spite of the slow growth of its core funding. External funding has increased very sharply indeed in the natural sciences, and the relative development has also been very favourable in the social sciences and the humanities. However, in the latter cases the baseline level for external funding was quite low.

Figure 3.4. Change in research expenditure from 1991 to 1998 in all universities and by field of science, in real terms (%).



Source: Statistics Finland.

In 1998, universities covered around 47 per cent of their R&D expenditure from outside sources (see Tables 3.4 and 3.5). In the same year the public sector accounted for 73 per cent of external funding to universities. The biggest single source of external funding in 1998 was the Academy of Finland, which provided funding worth around FIM 467 million. The sharpest increase in percentage terms is recorded for the National Technology Agency Tekes whose share increased from 1997 by around five percentage points to 23 per cent. Tekes funding totalled around FIM 371 million.

Universities differ quite widely in terms of the amount of external funding they have received. In 1998, the highest figure was recorded for the Tampere University of Technology (66%) and the Helsinki University of Technology (60%), the lowest for the Theatre Academy (3%) and the Sibelius Academy (11%). There are also differences in the share of external research funding between fields of science. In 1998, the proportion of external funding was highest in engineering and technology (59%) and in the agricultural sciences (57%). In the 1990s, the sharpest increase in external research funding has been recorded for the natural sciences and the social sciences.

Table 3.4. External research funding received by universities* by source of funding in 1998 (EUR 1 = approx. FIM 6).

	FIM million	%
Academy of Finland	467.1	29
National Technology Agency	370.9	23
Other public funding	341.6	21
Foundations	39.5	2
Business enterprises	167.7	10
Foreign countries	191.5	12
Universities' own funds	43.4	3
Total	1,621.7	100

* University hospitals not included.

Source: Statistics Finland.

Table 3.5. Amount of external funding and its share of universities'* research expenditure by field of science in 1998 (EUR 1 = approx. FIM 6).

	Research expenditure FIM million	External funding FIM million	External funding %
Natural sciences	1,114.7	594.9	53
Engineering and technology	702.9	413.1	59
Medical sciences	524.0	195.5	37
Agricultural sciences	80.2	46.0	57
Social sciences	699.8	266.8	38
Humanities	360.1	105.4	29
Total	3,481.6	1,621.7	47

* University hospitals not included.

Source: Statistics Finland.

The rapid increase in research expenditure is in large part explained by the Government's additional funding programme, the volume of which amounted to FIM 3.35 billion. In science policy terms, the funding decision was also motivated by the aim to strengthen high-quality scientific research especially in disciplines crucial to business in technology, the natural sciences and knowledge-intensive industries.

Most of the additional funds were channelled through Tekes (56%), i.e. the accent was clearly on applied research and product development. A total of FIM 635 million (EUR 107 million) (19%) was allocated directly to universities, the same amount was channelled through the Academy of Finland. A considerable proportion of the funds allocated to Tekes also filter through to university research. Overall, the Government programme has been absolutely crucial in strengthening the basic research infrastructure in universities.

The additional funds allocated to universities have gone towards strengthening the most successful graduate schools, to opening new graduate schools, acquiring new equipment, to developing network co-operation and data transfer mechanisms and to increasing expert training in mathematics, the natural sciences and technical fields. Additional funding through Tekes has been allocated to four specific uses: technology-oriented services, intersectoral cluster programmes, basic engineering research and new business operations. Additional funding from the Academy of Finland has been used to start up research programmes in strategically important fields of research, to strengthen centres of excellence in research and to create new centres, to launch the postdoctoral researcher system and promote professional research careers among young doctoral students, and to increase international research co-operation.

3.5 Strengthening universities

The strengthening of postgraduate training and the role of university research is an important national strategic objective, the implementation of which has balanced universities' activities in relation to the rest of the research system, allowed universities to adopt a distinctive profile in relation to polytechnics and clearly raised the standards of teaching and education in Finland. Having said that, it has certainly been a struggle for many universities to strike a balance between their increasing volume of research and increasing postgraduate training, on the one hand, and their reduced core funding, on the other. According to a working group that looked into the core funding of universities in 1999, the amount of money received by universities in 1998 was at roughly the same level as in 1991 (allowing for the effects of technical changes in budgeting as well as changes in real estate management). At the same time performance statistics indicate a huge increase in the operation of universities: the number of master's degrees has gone up by 35 per cent from 1991 to 1998, the number of doctorates by 88 per cent. During the same period the number of new students has risen by 13 per cent and the total number of students by 27 per cent.

A consistent and long-term development effort on the part of universities would require stable and steady growth of core funding. However, according the report of a working group studying the preconditions for research in Finland, this is not what has happened. Inadequate core funding seriously undermines the work that universities are doing to develop their teaching and research. Universities spend two-thirds of their budgets on wages and salaries, but they are reluctant to lay off people; this is nonetheless what they have had to do in trying to cope. To some extent they have also been cutting teaching resources in favour of research. This, however, is a dangerous path to follow, because a high standard of education is one of the key preconditions for high-quality research.

The focus of universities' cost-cutting exercises has therefore been on items other than wages and salaries. Core facilities have been a particularly problematic area in the 1990s: universities have had to try and cope with outdated research equipment, a serious shortage of scientific literature, and inadequate support services. Savings have been made most notably in library services and in the acquisition of research equipment.

According to the Development Plan for Education and Research (1999–2004), adequate core funding shall be guaranteed for universities so that they can continue their efforts for long-term development. At the same time the targets set for the university system shall be tied more closely to the amount of appropriations granted so that the assignment of new tasks and any expansion of education and research will increase the amount of core funding allocated. Indeed the Ministry of Education working group suggested that in view of the rising salary costs and expenditures in general, the validity of the third, resource paragraph of development legislation shall be extended so as to make sure there is no real decrease in the level of university appropriations. In addition, the working group recommends that the legislation should be revised to take account of the changes that have happened in the extent of university operations. If put into effect, these recommendations would guarantee the future funding of universities, but they would not bridge the gap that has been torn open in the volume of funding in the 1990s. For this reason the working group proposed that universities be granted an additional annual lump sum of FIM 110 million towards their operating expenditure in 2001–2006.

Competitive external funding is unreliable, short-term and tied to specific purposes. It is clear that universities cannot continue to expand and raise the quality of their operation simply on the strength of project funding or competitive financing. Some universities are also inclined to feel that external research funding constrains their autonomy. On the other hand, it is recognised that external funding does give them greater latitude in relation to the Ministry of Education, as they no longer have to rely exclusively on core funding from budget sources. However, it is clear that universities should not rely too heavily on outside sources because in the long term, they need to have some certainty about the continuity of funding.

Universities differ quite widely in terms of how much they invest in research. This is at least in part explained by their orientation. It is often easier for universities with a strong engineering, commercial, medical or natural science orientation to secure external research funding than it is for traditional multidisciplinary universities that rely more heavily on core funding for research purposes. The weight of different disciplines within universities is of key significance to the prospects of securing research funding. Within the university system art academies have succeeded in securing more research funding in the late 1990s. Art academies do not yet have the same kind of research and postgraduate training tradition as science universities, but the role of research is clearly increasing.

Growing concerns have been expressed in recent years about the impacts of external funding on the independence of universities and their goal-setting. The problem is also recognised in the Development Plan for Education and Research for 1999–2004, and it will certainly be receiving more attention in the future. The growth of external funding for universities must be based on the premise that this funding is in line with the objectives set for universities and with universal ethical principles. It is also clear that external funding must not jeopardise the independence of university research and teaching.

During the 1990s, growing attention has been paid to strengthening research environments. External funding allocated on a competitive basis has been of crucial significance to the output of research and to raising its quality standards. As far as universities themselves are concerned, the evaluation of scientific quality must always try to take into account the distinctive features of the discipline concerned. For instance, in many applied sciences the innovations emerging from research results and their impacts on the development of the national economy may be regarded as more important criteria than scientific productivity. The adoption of multidisciplinarity and innovativeness as key criteria is particularly important in new, emerging fields of research.

One of the strengths of the university system in the 1990s has been the intensification of postgraduate training and the doubling of the number of doctorates earned. The latter statistic clearly reflects the increase in university research. The national graduate school system is regarded at universities as a highly efficient and necessary way of giving young scholars the opportunity to gain the further qualifications they need. The system has also helped to raise the quality of further education in Finland. It has increased co-operation between universities, which in turn promotes the development of new kinds of innovative research environments. Collaboration with government research institutes has also increased in postgraduate training. For instance, government research institutes have joined forces with universities to create incentive systems whose purpose is to encourage researchers to complete their doctorate.

Postgraduate training in universities has greatly benefited from the growth of external funding, giving research projects the opportunity to recruit postgraduate students on their staff. The allocation of postgraduate training places to certain disciplines is a good way for universities to strengthen their areas of expertise. In the current situation, however, universities have not necessarily had the resources to support postgraduate training to the extent they might have wanted to. At the same time as the development of researcher training has brought more resources into research at a national level, it has curtailed the autonomy of universities in further training and significantly increased their costs.

Universities, too, have a vested interest in ensuring that the development of postgraduate training corresponds to the needs of society. It is hoped that if and when the target numbers for degrees are raised, that is preceded by an assessment of graduate placement. The increase in the numbers taking their doctorate puts increased pressure on opening new research posts at universities. Indeed, under the new University Act universities can now make their own decisions on new posts and positions. Nonetheless it is hoped that newly graduated PhDs could more often find employment outside the university system in positions requiring a high level of expertise.

Universities have recently committed themselves to the national centre of excellence policy. The research teams and units that are at the cutting edge of international research help to strengthen universities' own areas of expertise and their research profile. The status of centre of excellence in research is also important to universities.

The ongoing efforts of structural development have served to increase and strengthen collaboration among universities and encouraged flexible networking. There has been a conscious effort to try and find new organisational solutions that would support the emergence of research that moves with ease across disciplinary boundaries.

Departments working in the same or closely related fields of study have been merged to form larger units, and multidisciplinary research units and science parks have been set up. Libraries have also been combined so that they can be shared by more than one department. Inter-departmental training programmes and other joint projects have paved the way to multidisciplinary development of education and research.

Steps have also been taken to intensify co-operation between universities and polytechnics operating in the same region, as well as between the same fields of study in different universities. This has at once helped to clarify the existing division of labour. In addition, regional co-operation has allowed universities more flexibly to respond to local educational needs. Universities have a significant positive impact on the society around them, and consequently the requirements of social relevance imposed upon them have increased. Good examples of the local and regional impact of universities are provided by the universities of eastern Finland (in Joensuu, Lappeenranta and Kuopio), which according to an evaluation by a group of international experts have made a very significant contribution to regional development in their respective fields of expertise and which are widely recognised as highly influential and significant actors by local stakeholders (see also Chapter 4.2.2).

One of the ways in which universities have sought to increase their impact and the relevance and exploitation of research results has been to increase co-operation with the business sector. This is in fact one of the key strengths of Finnish universities. Co-operation and networking has increased and deepened. One example of this is provided by the growing number of endowed professorships. Today the most popular branch is the information industry, which is also supported by a Ministry of Education programme to increase training places in this field. In their own areas of expertise universities are involved in regional know-how centres. Science parks and centres that promote and inspire small business play a key role in creating contacts between research and business and industry. Special service centres supporting research-oriented business and innovation have also been set up in universities. Recruitment services designed to promote graduate placement serve as an important link between universities and business companies. Many universities have their own research and business ombudsmen, whose job it is to help local businesses make the best possible use of the research and product development services offered by universities.

The growth of international co-operation has an important role to play in promoting the emergence of new kinds of research environments. Visits by university teachers and researchers to foreign countries have increased significantly in the 1990s. At the same time the number of foreign visitors to Finland has also increased markedly. This applies most notably to short, two-four week visits abroad and into Finland. Visits out of and into Finland have also increased among students. Student exchange takes place primarily through EU exchange programmes and on the basis of bilateral agreements between universities.

International exchange and interaction is very much an integral part of everyday life at universities. In particular, involvement in research projects under EU framework programmes has increased the co-operation that Finnish universities have with foreign universities, research institutes and companies. One of the ways in which universities have sought to promote internationalisation in the field of research has been by way of participating in different networks of co-operation. For instance, the University of Turku is co-ordinating a national university network programme with the Baltic states; the pilot project in this programme is the Baltic Sea Regional Studies training programme. The Arctic Centre at the University of Lapland, for its part, is co-ordinating preparations for a virtual network university, which will involve universities and institutions from Northern countries of the world. The University of Joensuu has joined the European Consortium of Innovative Universities network, the aim of which is to set up joint research and education projects and to increase the collaboration of universities with the business sector.

3.6 The future role of universities

One of the future challenges for universities is presented by the question of how they can fit together the bottom-up strategies emerging from different disciplines and from different value foundations, the views of university management, the priorities of national science and technology policies and the needs of funding bodies and especially those of business and industry.

Interdisciplinary and multidisciplinary approaches are currently gaining ground in scientific research, and there is a growing need in society for researchers with a broad knowledge base and good problem-solving skills. One of the main avenues that universities will need to follow in the future is to promote basic and postgraduate education and research that cuts across disciplinary boundaries. At the same time, they will need to continue their efforts at specialisation and strengthen their know-how in their special areas of expertise. One of the ways to reach the international forefront of research and to cope under the pressures of stiffening competition is to have a clear division of labour within the university system. Specialisation in certain disciplines and the creation of a strong profile are seen at universities as a challenge that may at once involve serious threats related to the development of science policy or society. The main threats are represented by the scarcity of basic resources, the lack of diversity in research and education and the allocation of research funds to selected disciplines.

Universities are actively involved in regional development efforts and in the promotion of welfare. Indeed it is a widely shared view among universities today that one of their most important future challenges is to strengthen their impact locally, for instance in terms of the education opportunities they offer: this is highly significant in terms of attracting people and business into the region. Universities influence the local industrial structure by producing expertise and creating jobs in certain areas. The aim is to make available the knowledge and know-how generated within the university as quickly and as effectively as possible so that local companies can benefit. A good example of the regional impact of universities is provided by the country’s growth centres. Universities are also keen to make a positive impact on the cultural and social welfare in their region. They like to see and portray themselves as highly influential agents in terms of social development and as leading experts in their respective fields of specialisation, with close contacts to the surrounding society.

Universities have tried flexibly to adapt to the dramatic increase in external funding by diversifying their funding structures and mechanisms. It remains to be seen how the content and the quality of research will be affected. Structural development efforts will also need to be continued: for instance, serious questions will need to be asked about the role of the large number of different units that universities continue to operate.

A special cause of concern for the future is that the requirements of commercial viability seem to be taking precedence over the promotion of knowledge and civilisation as well as the old Humboldtian ideal of the unity of teaching and research. The changing structures and functions of universities reflect the tendency for the boundaries between basic and applied research to become more and more blurred. In spite of this, universities feel that their most important task in the innovation system is to do high-quality research, which forms a solid basis for applied research and the development of technology. For universities, the best way to support and develop is to strengthen research and the basic preconditions for doing research on as broad and equal a basis as possible.

4 Output and impact of research

The basic functions of universities have traditionally been to conduct scientific research and to provide research training as well as undergraduate education. Now, universities are also expected to show a stronger commitment to various needs and expectations of society, to collaboration with other conductors of R&D and to users of research findings. To some extent all these functions overlap and interact and, in this sense, are mutually supportive. Research also produces results and impacts that often are closely interwoven and impossible to distinguish from one another. For instance, the training of new researchers, the growth of tacit knowledge and the mobility of researchers in the labour market is a process that may be regarded as the result or outcome of research, as a mechanism through which research results are disseminated or as research impacts.

The expectations pinned on research and universities are concretised in an examination of the targets set for their output and impact. Most key policy decisions concerning the science system are made by the Science and Technology Policy Council and the Ministry of Education. The general objectives identified in their reports and development plans may be seen as the foundation on which other output and impact targets for scientific research are based.

The Science and Technology Policy Council noted in 1996 that it is essential for Finland to continue to invest in knowledge and know-how and their utilisation: that is the only viable path to economic, social and cultural development. As far as universities were concerned the key objectives were the development of the science system as an integral part of the innovation system; the development of environments that would support high-quality research; the creation of centre of excellence networks; the deepening of international co-operation; and increased investment in research funding (Finland... 1996). The targets identified in the Government's additional funding programme (see Chapters 1 and 2) were based primarily on the policy lines set out by the Science and Technology Policy Council. Other objectives included in the programme for universities were to strengthen graduate schools and start up new schools; upgrade the research equipment in universities; improve the preconditions for research; develop data transfer mechanisms; and increase expert training in mathematics, the natural sciences, and engineering and technology (Valtion... 1999).

In its Development Plan for Education and Research in 1995–2000 (Koulutus... 1995), the Ministry of Education says that key development objectives as far as scientific research is concerned include the attainment of high quality standards, freedom of research, a high ethical standard and a balance between basic and applied research. According to the Ministry of Education plan, a flexible and comprehensive system of research and education and the specialisation of universities in certain areas of expertise provide the basis on which research and education can advance to the international forefront. It is also considered essential that universities help to create and establish centres of excellence in research, to promote young researchers' careers and promote joint research projects between universities and business companies that support the regeneration of industrial activity. The general science policy goals set for the science system, the development efforts related to research output and impact as well as their implementation have been discussed in previous chapters of this report. This chapter reviews the impact of research particularly from the viewpoint of scientific publications and their citations. It also analyses different forms of research impact providing both domestic and international examples.

4.1 Forms and mechanisms of output and impact

Opinions vary quite widely on the role and impact of scientific research (and basic research in particular) in society. The traditional view has it that science and research play a key part in the production and accumulation of new knowledge, in the formation of a rational world-view, in society's self-assessment as well as in increasing our understanding of different phenomena. Universities and scientific research have thus established the institutional foundation for civilisation, curiosity and new knowledge. However, this view no longer provides a sufficient justification for the development of the science system or for the allocation of resources into research.

Basic research helps to promote both scientific as well as social, technological and economic development. However, the benefits and impact of research are primarily of an indirect nature. Investments in scientific research are justified among other reasons because research generates (e.g. Pavitt 1991; Rosenberg 1992; Martin et al. 1996; National... 1998):

- new information about the basic characteristics and mechanisms of different phenomena as well as information that confirms or refutes theories based on prior knowledge;
- new research tools, methods and techniques that can be adopted throughout society;
- competent new people on the labour market, especially for knowledge-intensive jobs and occupations requiring special skills and expertise;
- information to support political decision-making;
- information for the assessment of different measures in society and the broader social, cultural and ecological impacts of technology;
- information that may generate technological solutions differing significantly from earlier solutions or leading to new scientific questions;
- intellectual capital that may lead to breakthroughs in applied research and product development.

In any analysis of the outputs and impacts of research, we need to draw attention to the interaction between science and technology. This has to do with understanding phenomena and with the links between approaches that emphasise the function of use. The exchange and transfer of information between science and technology is a two-way process. Even though there is some measure of overlap, the concepts of *science* and *technology* are nonetheless clearly distinct and should be kept strictly apart. According to the classical view, the main flow of things runs from the former to the latter: scientific research and its outcomes impact technological development, while there is less interaction in the opposite direction. This, however, has proved to be a very restricted interpretation.

Among other things, scientific research gives technology: a) new information that serves as an immediate source for new technological ideas and more efficient tools and techniques; b) research equipment, laboratory techniques and methods of industrial and technological development; c) tacit knowledge that is needed in the creation and development of new technologies; and d) a knowledge base for the assessment of technological impacts and more efficient strategies for applied research and development. Technology, for its part, gives scientific research: a) new scientific questions and research materials; b) information that can help steer scientific research in a more meaningful direction and towards a more meaningful balance between different fields of research; c) new equipment and techniques that can help resolve scientific questions (e.g. Narin & Olivastro 1992; Rosenberg 1992; Brooks 1994). It is also important to note that the links between scientific research and technology can at once stimulate basic research, applied research and development work. In certain fields (such as in the life sciences), the differences between science and technology as well as between basic and applied research are blurred, and the different activities become quite closely tied to one another. Therefore, if a laboratory, for instance, shifts its emphasis from purely basic research in a more applied direction, that will not necessarily slow down its scientific development, at least in the short term. In fact, the change may have quite the opposite effect (e.g. Cohen 1995).

A distinction may be made between the following types of research impacts:

- Scientific – for instance the accumulation and renewal of knowledge and know-how.
- Technical – for instance new technological solutions and improvements, new products and processes, patents.
- Societal – (a) social and cultural impacts, which are seen for instance in domestic or international debate; (b) regional impacts, which are seen in an analysis of the significance of universities to their immediate environment; (c) political impacts, which have to do with the exploitation of results and the use of the expertise of research scientists in political decision-making; d) organisational impacts, which are seen for instance when new models and structures suggested by researchers in such fields as administrative sciences, political science, economic and business administration or communication studies, are introduced in society and in politics.
- Economic – the outcomes of scientific research have an indirect impact, for instance, on the development of high-tech products and production and, furthermore, on the foreign trade.

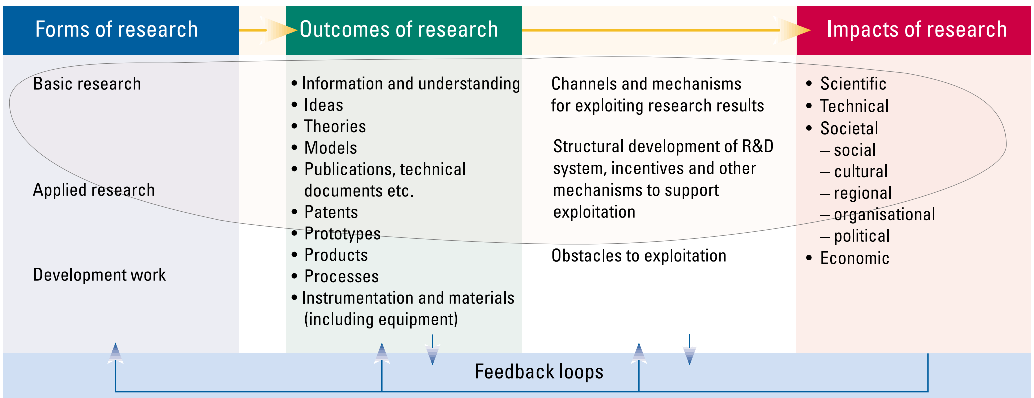
Research in such fields as the medical sciences, the social sciences, environmental sciences and in the social work sector have an impact of their own on political decision-making. These impacts may spread quite widely throughout society, even though they may remain of an indirect nature. The process is often channelled through the mass media, which will give good coverage and exposure to interesting research results and in this way generate public debate. This in turn increases general awareness about the findings, which may affect people's behaviour; if political decision-makers are convinced, it may also bring more resources into that particular field of research or lead to other measures.

The diversity of research outputs and impacts is clearly reflected in the support offered by university researchers and teachers to the operation of society through their reports and statements, through their involvement in various bodies and working groups, their participation in civic activity and their public appearances to take a public stance on issues (e.g. Wilhelmsson 1999). This aspect of scientific activity is one on which there is very limited systematic information. It is also an aspect that is very hard reliably to measure or classify, even if there might be an interest to do so.

The associations between research output, the dissemination of research results and their impacts are outlined in Figure 4.1. Chapters 4.2–4.4 below focus especially on the factors that lie within the marked area in the Figure. The connections between the forms, outcomes and impacts of research vary and are highly complex processes. For this reason, it has to be stressed that the feedback loops shown in the Figure and the mechanisms and channels of exploiting scientific research are crucial with respect to the transfer of knowledge and know-how. These kinds of mechanisms and channels may include:

1) measures that promote networking among companies and researchers (regional centres set up for the promotion of technology, biocentres, cluster projects);
2) activities that support technology transfer, patenting, licensing and the growth of spin-off companies (technology transfer organisations and companies, universities' research and innovation ombudsmen, universities' own or affiliated business incubators);
3) legislation that supports the exploitation of research results (e.g. questions related to intangible rights);
4) measures that support and encourage active collaboration among researchers and end-users of research results. Other channels and mechanisms of exploiting research results include publications, technical reports and non-public documents and various forms of tacit knowledge transfer, such as a) education, b) meetings, seminars, conferences, etc., c) consultation, expert services and commissioned research and d) researcher mobility in the labour market.

Figure 4.1. Research work: forms, outcomes, dissemination of results and impacts. ®



4.2 Evaluation of research output on the basis of publications and citations

The output or productivity of scientific research may be defined as referring to the success that researchers have in attaining the goals and objectives that are considered valuable in the scientific community, i.e. achievements that significantly increase our scientific understanding and/or that may lead to new useful applications. New ideas and new hypotheses and theories based on these ideas pave the way for the work and efforts of other researchers. However, it is very often difficult accurately to demonstrate an advance in scientific understanding. It is particularly difficult to assess the impact of a specific result or individual researcher on the development of science. Likewise, it is often virtually impossible to trace the individual scientific findings that lie behind useful applications.

Any piece of research that is published in a scientific journal has to be reviewed by independent experts. The number of articles published in refereed journals may be regarded as one indicator of the performance or productivity of an individual researcher, research team, department, branch or field of research or country. To some extent, the scientific impact of an individual publication can be assessed on the basis of the general esteem of the journal that has published the paper. That in turn is assessed (at least within the discipline concerned) in terms of how many citations the papers published by the journal receive during a certain period of time. The number of citations is also used in assessing the respect commanded by an individual publication, researcher, research organisation or academic research in a certain country.

The interpretation of indicators based on numbers of publications and citations is not entirely unproblematic (see Appendix 1; further see e.g. Okubo 1997). Publication and citation practices vary from one discipline to the next, which is why bibliometric science indicators should not be used in comparisons of research in different disciplines. In addition, some disciplines tend to publish large numbers of monographs which are not covered by bibliometric databases (like ISI's NSIOD, see below). Many international publication and citation databases also have an inherent structural bias: the vast majority of publications included in the databases are in the English language. Yet in many fields of research in the humanities and the social sciences, research is reported in the language of the country in question. In addition, it is often considered more valuable and useful to publish in domestic series than in other countries' national journals.

A common problem with co-authored publications is the question of who should be credited. Co-authored publications are particularly common in the natural sciences and medical sciences, where the biggest credit usually goes to the first or last author. In the case of publications co-authored by researchers from several different teams, departments or countries, there is the corresponding difficulty of identifying the community that deserves the greatest credit. Practices in this regard may have been affected by the increasing use of publication and citation indicators as criteria of resource allocation.

4.3 Scientific publishing in Finland and other OECD countries

The discussion below looks at the number of publications issued[1] and the number of citations received by Finnish researchers and compares these figures with the corresponding statistics for other OECD countries. Publication numbers are also examined in relation to population number, GDP (Gross Domestic Product) and the R&D expenditure of universities and research institutes. The respect commanded by research is assessed by comparing the number of citations received by Finnish publications to the total number of publications and by comparing these figures to the corresponding statistics for other countries. The purpose is to provide an overview of the output, productivity, quality and impact of Finnish research that allows for international comparison. The base figures for these comparisons are the total numbers of publications and citations recorded for the OECD countries and the number of publications and citations by the six major fields of science. The classification of disciplines and fields of research is based on the OECD categorisation (natural sciences, medical sciences, engineering and technology, agricultural sciences, social sciences, and humanities). The number of publications and citations are obtained from a database maintained by the US-based Institute for Scientific Information (ISI), the *National Science Indicators on Diskette* (NSIOD) 1981–1999. The database and the science classification used are described in closer detail in Appendix 1.

4.3.1 Finnish research in international scientific series 1981–1999

The number of scientific publications with Finnish authors in the 1999 NSIOD database was higher than ever before. In 1999, Finnish researchers published almost 7,000 papers, which was twice as much as in 1986. The figures have been rising for quite some while (Figure 4.2, Table 4.1) In 1981, the number of papers was around 2,600, in 1983, the figure was over 3,000. Since the early 1990s, the numbers have increased quite dramatically: the 4,000 mark was reached in 1991, 5,000 in 1994 and 6,000 in 1996.

The number of Finnish publications as a proportion of world publications has also shown strong and sustained growth. In 1999, Finnish researchers accounted for 0.95 per cent of world publications. During the 1980s, there was very little movement in the figure, which remained steadily in the region of 0.6–0.7 per cent. From 1990 onwards, however, there has been strong growth. As in the case of Finland's share of publications, the country's share of all citations showed relatively slow growth in the 1980s. That figure began to rise very quickly in 1991. Since this same year, Finland's share of world citations has been markedly higher than its share of publications.

Table 4.1 describes the trends for Finnish publication and citation numbers in three five-year periods during 1981–1999[2]. This method of analysis evens out the effects of year-

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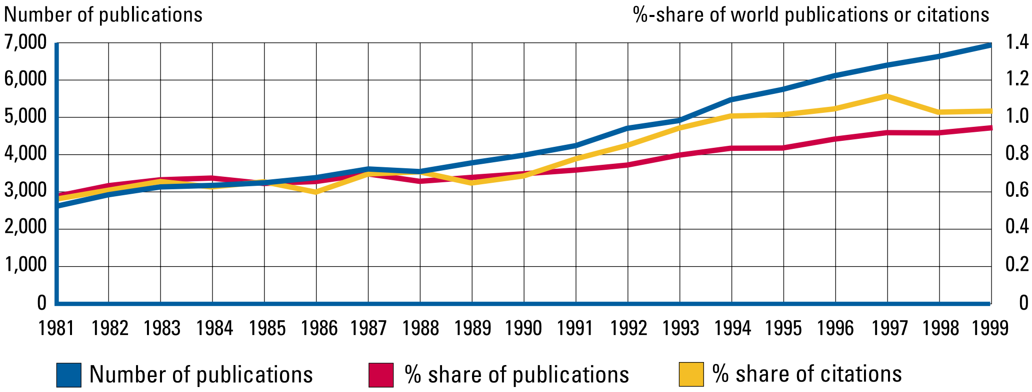
1 The data (statistics) include publications by researchers based in Finland and co-authored publications in which at least one author is based in Finland. The key criterion is that the contact information provided in the paper lists at least one Finnish address.

2 The figures in this Table indicate how many papers have appeared in each five-year period and how many citations they have received during the period concerned. The figures do not include citations received after the period analysed, and therefore differ from the data presented in Table 4.7. Table 4.7 shows the total accumulation of citations received by papers during 1981–1999.

■ Figure 4.2. Number of Finnish publications and the share of publications and citations as a proportion of world publications and citations 1981–1999.



Source: Institute for Scientific Information, NSIOD 1981–1999.

to-year fluctuations. In 1995–1999, Finnish researchers published some 31,900 papers, representing 0.91 per cent of world publications. In 1988–1992, Finland accounted for 0.70 per cent of world publications, while in the 1980s, the figures were around 0.65 per cent. The number of publications has shown rapid growth during the past 20 years. In 1995–1999, the number of publications was 57 per cent higher than in 1988–1992. The increase in the number of publications from 1981–1985 to 1988–1992 was 33 per cent.

■ Table 4.1. Finnish scientific publications and citations received by these publications: numbers, trends and shares of world publications and citations in 1981–1985, 1988–1992 and 1995–1999.

	1981–1985	1988–1992	1995–1999
PUBLICATIONS:			
Number of publications	15,232	20,285	31,907
% increase in number of publications to previous period under review	–	33.2	57.3
% share of world citations	0.65	0.70	0.91
CITATIONS:			
Number of citations	41,005	61,809	140,731
% increase in number of citations to previous period under review	–	50.7	127.7
% share of world citations	0.63	0.69	1.05
Impact factor*	2.69	3.05	4.41
Relative citation impact**	0.97	0.98	1.15

* Impact factor = number of citations/number of publications.

** Relative citation impact = The impact factor for Finland / the impact factor for the world (e.g. in 1995–1999, the impact factor for Finland was 4.41 and for the world 3.82, i.e. the index value is 4.41 / 3.82 = 1.15).

Source: Institute for Scientific Information, NSIOD 1981–1999.

Finnish publications appearing in 1995–1999 received a total of more than 140,000 citations during this same period. This was some 128 per cent more than in 1988–1992 and almost 3.5 times more than in 1981–1985. In 1995–1999, Finland's share of world citations was 1.05 per cent[3]. Compared to 1988–1992 (0.69%), this figure has shown rapid growth. The indicators describing the visibility and impact of research, i.e. the impact factor and relative citation impact (or index) have also developed favourably. In recent years, the citations received by publications produced in Finland have shown much faster growth than in the world on average. In 1981–1985 and 1988–1992, the relative citation impact came close to the world average, i.e. impact value 1. In 1995–1999, the number of citations received by Finnish publications was 15 per cent higher than in the world on average (impact 1.15).

The picture that is drawn on the basis of ISI data can be complemented by information obtained from the KOTA database maintained by the Ministry of Education. KOTA figures indicate that in 1994, researchers in Finland published 18,020 and in 1998 a total of 20,747 papers[4]. In peer-reviewed scientific series, the total number of papers published in 1998 was 10,235, while four years previously the figure was 9,838. In 1998, less than 1,800 papers were published in Finnish series, while the figure in 1994 was over 2,300. The numbers for foreign journals in 1994 were over 7,500 (NSIOD indexes 5,448 papers, or 73% of the number indicated by KOTA) and in 1998 almost 8,500 papers (NSIOD 6,632 or 78%).

A comparison of ISI and KOTA data indicates that the number of papers published in domestic scientific journals and their share of all scientific publications by Finnish authors has clearly decreased. In corresponding foreign series, the situation with regard to published articles is exactly the opposite. However, the growth rate for the number of papers published by Finnish researchers in ISI-indexed foreign journals has been much faster in 1994–1998 and the trends have shown more stable growth than suggested by KOTA data. This indicates that publishing by Finnish researchers – i.e. their publishing profile – has become much more internationalised. Researchers publish more often than before in well-known and respected journals. Finnish science policy has long been aimed at raising the standards of scientific publishing and at increasing its visibility, and considerable efforts have been invested in developing the research environment with the specific view of attaining this objective. In the light of the figures reviewed above, there has been relatively good success in this regard.

Table 4.2 shows the country profile for Finnish publishing in four cross-section years, i.e. the number of publications in different fields of science and trends, share of world publications and relative publication indices. In 1999, most of the Finnish publications were in the natural sciences (45% of all Finnish publications) and in the medical sciences (40%). The shares of all other fields of science are considerably smaller: engineering and technology accounted for seven per cent, the social sciences for around five per cent and the agricultural sciences for around two per cent. The share of the

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3 Looking at individual years, we find that Finland's share of all citations exceeded one per cent (1.01) as early as 1994.

4 The figures include articles reported by university researchers in domestic and foreign scientific journals, contributions to readers and proceedings, monographs and papers published in university series.

Table 4.2. Finnish publishing profile: key indicators of publishing in major fields of science for 1981, 1987, 1993 and 1999

Field of science / Year	1981	1987	1993	1999
Natural sciences				
Number of publications	1,165	1,503	2,328	3,502
Share of all Finnish publications	41.2%	38.2%	42.7%	45.2%
Relative (%) increase in the number of publications to the previous year under review	–	29.0%	54.9%	50.4%
Share of world publications in the field	0.49%	0.55%	0.70%	0.89%
Relative publication index*	0.85	0,79	0.88	0.94
Engineering and technology				
Number of publications	165	170	394	541
Share of all Finnish publications	5.8%	4.3%	7.2%	7.0%
Relative (%) increase in the number of publications to the previous year under review	–	3.0%	131.8%	37.3%
Share of world publications in the field	0.45%	0.38%	0.63%	0.69%
Relative publication index*	0.76	0.55	0.79	0.72
Medical sciences				
Number of publications	1,297	1,938	2,335	3,103
Share of all Finnish publications	45.8%	49.2%	42.9%	40.1%
Relative (%) increase in the number of publications to the previous year under review	–	49.4%	20.5%	32.9%
Share of world publications in the field	1.00%	1.20%	1.22%	1.32%
Relative publication index*	1.71	1.72	1.52	1.39
Agricultural sciences				
Number of publications	102	127	149	148
Share of all Finnish publications	3.6%	3.2%	2.7%	1.9%
Relative (%) increase in the number of publications to the previous year under review	–	24.5%	17.3%	–0.6%
Share of world publications in the field	0.65%	0.88%	0.98%	0.93%
Relative publication index*	1.11	1.26	1.23	0.98
Social sciences				
Number of publications	73	163	188	379
Share of all Finnish publications	2.6%	4.1%	3.5%	4.9%
Relative (%) increase in the number of publications to the previous year under review	–	123.3%	15.3%	101.6%
Share of world publications in the field	0.19%	0.39%	0.40%	0.71%
Relative publication index*	0.32	0.56	0.51	0.74
Humanities				
Number of publications	28	35	54	70
Share of all Finnish publications	1.0%	0.9%	1.0%	0.9%
Relative (%) increase in the number of publications to the previous year under review	–	25.0%	54.3%	29.6%
Share of world publications in the field	0.18%	0.21%	0.32%	0.40%
Relative publication index*	0.30	0.30	0.40	0.42
Total				
Publications**	2,830	3,936	5,448	7.743
Real number of publications and the level of overlapping	2,635 (7.4%)	3,625 (8.6%)	4,923 (10.7%)	6,980 (10.9%)

* Relative publication index = The number of publications in the field of science as a proportion of all publications in Finland/ the number of publications in the field of science as a proportion of all publications in the world. E.g. the index value of natural sciences in 1999 was 0.94, i.e. natural sciences accounted for six per cent less of all publications in Finland than they did in the world on average. In medical sciences on the other hand, Finns published 39 per cent (index 1.39) more than the world average.

** The note is due to the qualities of ISI's NSIOD database. As the database is first searched for publication and citation data by an individual field of research and field of science, and the data retrieved is then combined to larger groups, some of the publications may be counted twice. The total numbers of publication, received by summing up the numbers of publication in all major fields of science, are therefore bigger than those retrieved from the database by an overall search.

Source: Institute for Scientific Information, NSIOD 1981–1999.

humanities was about one per cent. There have been some changes in these shares over the past two decades. For instance, the share of the natural sciences has increased by some seven and that of engineering and technology by some three percentage points from 1987 to 1999. The share of the medical sciences, by contrast, has declined by around nine percentage points. In other major fields of science the changes have been smaller, amounting to less than 1.5 percentage points.

All major fields of science have shown a marked increase in publishing activity. In the 1980s, two major fields stand apart from the rest of the field, i.e. the social sciences (where in 1981–1987 the number of publications increased by 123%), and engineering and technology (which recorded a growth rate of no more than 3%). From 1993 to 1999, the number of papers increased most sharply in the social sciences and in the natural sciences. In engineering and technology, the medical sciences and in the humanities, the increase was in the region of 30–40 per cent. The agricultural sciences recorded no growth.

In all major fields of science, the figures as a proportion of world publications have shown very strong growth since the early 1980s. The medical sciences have consistently recorded the highest proportion of all publications in their respective fields (1.32% in 1999). However, in relative terms, the growth has been strongest in the social sciences, the humanities and the natural sciences. In 1981–1999, Finland's share of world publications increased in the social sciences from 0.19 per cent to 0.71 per cent, in the humanities from 0.18 per cent to 0.40 per cent and in the natural sciences from 0.49 per cent to 0.89 per cent. Engineering and technology and the medical sciences have shown rather positive trends of growth.

Compared to other countries Finland's publishing profile clearly leans more heavily towards in the medical sciences. In 1999, the number of publications in this field as a proportion of all publications in Finland was 39 per cent higher than the share of these disciplines of all publications in the world (index value 1.39). However, the trends in this share have been on the decline: in the 1980s the relative publication index was still around 1.7. At that time, the agricultural sciences still accounted for a relatively large share of all publications in Finland (index 1.11–1.26). In 1999, the social sciences in Finland accounted for 26 per cent less of all publications than they did in the world on average. The share of engineering and technology was 28 per cent and that of the humanities 58 per cent lower than in the world on average.

In the case of the humanities and the social sciences the relatively low shares of world publications and the low relative publication index are explained in part by the make-up of the ISI database[5]. This is also clearly in evidence in the international comparisons described under Chapter 4.2.2. At the same time, it is important to stress that although Finland does not seem to have a very strong position in the light of

5 The large English-speaking countries of the world and the United States in particular occupy a dominant position in the ISI databases (see Appendix 1). For instance, in 1997, the US together with the United Kingdom, Canada and Australia accounted for 69 per cent of all publications in the humanities and for over 81 per cent of those in the social sciences. The bias may be even greater in individual disciplines or fields of research: while the United States accounts for around 38 per cent of all publications in the database, its proportion in law is 89 per cent, in education 63 per cent and in economics 60 per cent.

these indicators, these fields have succeeded quite well in comparison with other OECD countries and for instance in terms of the relative citation impact (see e.g. Table 4.11).

In individual fields of research, Finland's shares of the world's publications in 1995–1999 were highest in the following ISI fields: environmental medicine (2.81%), endocrinology (metabolism 2.75%; nutrition 1.70%), rheumatology (2.74%), dentistry and oral surgery (2.43%), reproductive medicine (2.31%), otolaryngology (1.81%), clinical psychology (1.79%), general and internal medicine (1.74%), anesthesia and intensive care (1.73%), psychiatry (1.69%), clinical immunology (1.69%), laboratory medicine and medical technology (1.66%), medical research on organs and systems (1.65%) and environmental science and ecology (1.61%).

Table 4.3 shows the relative citation impacts in individual fields of research for 1995–1999 and 1985–1989. These figures compare in percentage terms the number of citations received by the country's publications in relation to the world average. The analysis excludes those fields where the average number of publications was less than 10 a year: in these fields the relative citation indices often showed very considerable fluctuations. For this reason, a large part of the humanities and the social sciences and certain fields of engineering and technology are not included in the analysis. In 1995–1999, Finnish studies received particularly frequent citations in general and internal medicine (citation impact 1.99, i.e. the number of citations per publication exceeded the world average by 99 per cent), in pharmacology and toxicology (1.59), gastroenterology and hepatology (1.56), foods and nutritional sciences (1.54), and in laboratory medicine and technology (1.54).

The main result of Table 4.3 is that there is a growing number of fields in which the relative citation impact exceeds value 1. Out of the 80 fields of research included in the analysis, 27 in Finland had a number of citations per publication exceeding the world average in 1985–1989; by 1995–1999, that figure had increased to 50 fields. At the same time as the Finnish publication production has shown strong growth, the impact of research has continued to increase and its quality to rise. In many fields, Finnish research enjoys greater international visibility and respect than ever before. This can be attributed, in no insignificant measure, to the rapid growth of international research collaboration during the past 15 years. This is seen in the increasing number of joint publications with foreign researchers. In 1998, co-authored papers accounted for 40 per cent of all Finnish publications, in 1986 the figure was still less than 20 per cent (see Persson et al. 2000: 20–22, 36).

4.3.2 International comparison

Publication and citation number and their development

In 1999, a total of over 730,000 titles were published in the international scientific series indexed by the ISI. Finnish researchers accounted for 6,980 of these titles, or 0.95 per cent of all publications (see Tables 4.4 and 4.5). The number of publications from Finland was 17th highest in the OECD group. In a Nordic comparison, Sweden (14,753 publications; 2.01%) and Denmark (7,453 publications; 1.02%) were still ahead of Finland in 1999.

Table 4.3. Fields of research in which Finland's relative citation impact exceeded the world average (i.e. impact value over 1) in 1995–1999 and 1985–1989.

1995–1999	Relative citation impact	1985–1989	Relative citation impact
Agricultural Chemistry	1.27		
Agriculture / Agronomy	1.12		
Anesthesia & Intensive Care	1.17		
Animal Sciences	1.40	Animal Sciences	1.24
Applied Physics / Condensed Matter /Materials Science	1.08	Applied Physics / Condensed Matter/Materials Science	1.17
Biology, General	1.09	Biology, General	1.06
Biotechnology, Applied Microbiology	1.22	Biotechnology, Applied Microbiology	1.57
Cardiovascular & Hematology Research	1.21		
Cardiovascular & Respiratory Systems	1.40		
Chemical Engineering	1.13		
Clinical Immunology & Infectious Disease	1.27		
Dentistry / Oral Surgery & Medicine	1.19	Dentistry / Oral Surgery & Medicine	1.16
Dermatology	1.37	Dermatology	1.57
Ecology / Environment	1.12	Ecology / Environment	1.30
Endocrinology, Metabolism & Nutrition	1.28	Endocrinology, Metabolism & Nutrition	1.07
Endocrinology, Nutrition & Metabolism	1.47	Endocrinology, Nutrition & Metabolism	1.02
Engineering Mathematics	1.45		
Environmental Medicine & Public Health	1.24	Environmental Medicine & Public Health	1.14
Experimental Biology	1.38		
Food Science / Nutrition	1.54	Food Science / Nutrition	1.16
Gastroenterology & Hepatology	1.56		
General & Internal Medicine	1.99	General & Internal Medicine	2.07
Hematology	1.04		
Information Technology & Communications Systems	1.21	Information Technology & Communications Systems	1.29
Instrumentation / Measurement	1.30	Instrumentation / Measurement	1.31
Mathematics	1.07	Mathematics	1.15
Mechanical Engineering	1.06		
Medical Research, Diagnosis & Treatment	1.30		
Medical Research, Organs & Systems	1.07		
Metallurgy	1.01	Metallurgy	1.18
Molecular Biology & Genetics	1.20		
Neurology	1.34	Neurology	1.06
Oncogenesis & Cancer Research	1.02	Oncogenesis & Cancer Research	1.02
Oncology	1.22	Oncology	1.15
Ophthalmology	1.17		
		Optics & Acoustics	1.08
Organic Chemistry / Polymer Science	1.14		
Orthopedics & Sports Medicine	1.45	Orthopedics & Sports Medicine	2.16
Otolaryngology	1.03	Otolaryngology	1.16
Pediatrics	1.44	Pediatrics	1.39
Pharmacology / Toxicology (clinical medicine)	1.13		
Pharmacology & Toxicology	1.59	Pharmacology & Toxicology	1.28
Physics	1.45	Physics	1.59
		Public Health & Health Care Science	1.23
Radiology, Nuclear Medicine & Imaging	1.01		
Reproductive Medicine	1.03		
Research / Lab Medicine & Medical Technology	1.54		
Rheumatology	1.06		
Spectroscopy / Instrumentation / Analytical Science	1.02		
Surgery	1.12		
Urology & Nephrology	1.42		
Veterinary Medicine / Animal Health	1.37	Veterinary Medicine / Animal Health	1.36
All Fields	1.15	All Fields	0.97
50 fields out of ISI's 80 fields.		27 fields out of ISI's 80 fields.	

Source: Institute for Scientific Information, NSIOD 1981–1999.

By far the largest number of publications in 1981–1999 was produced in the United States. In 1999, a total of more than 250,000 American papers were published, almost 35 per cent of the world's papers. Next in line were the United Kingdom (some 69,200 publications, 9.5% of world publications), Japan (68,800 publications; 9.4%), Germany (64,400; 8.8%) and France (47,400; 6.5%). During 1981–1999, the combined share of the five biggest 'research nations' in world publications has remained more or less unchanged, i.e. over 60 per cent. In other words, their position as major forces in research is a fairly solid one. In 1995–1999, the share of world publications increased most in Germany (0.82 percentage points) and in Japan (0.77 percentage points). In contrast to the situation in other OECD countries, the trends in publication numbers in the US and Canada have shown some decline in recent years, and their share of the world's publications has also gone down.

During 1991–1999, the number of Finnish publications increased on average by 6.4 per cent a year (Table 4.6). This was the ninth highest figure in the OECD group. In Finland, the increase in the number of publications was faster in the 1990s than in the 1980s, when the average annual rate of growth was 4.6 per cent. In 1991–1999, the countries that were ahead of Finland in this comparison were mainly emerging economies and/or countries that in terms of their research infrastructure were still lagging behind the top nations in the world, such as Turkey, Korea, and Mexico. Austria, Spain and Ireland were also ahead of Finland. The increase in publication volumes in the 1990s was much more moderate in countries with the highest levels of research expenditure, such as in the United Kingdom, Japan, France and Germany (averaging 3.9–5.1% a year).

The total number of citations received by scientific publications in OECD countries and their shares of world citations in 1981–1999 are shown in Tables 4.7 and 4.8. It is important to exercise caution in an investigation of the total numbers of citations and shares of citations, because the information in the database is complemented each year with data from previous years. This is clearly seen in Table 4.7, which shows the number of citations for the OECD countries from 1981 to 1999 (see also Footnote 2). The total number of citations peaks in 1990 at almost 7.8 million citations, and then begins to fall off. Papers published in 1999 have enough time to receive over 200,000 citations[6].

As is the case with publishing volumes, American publications are well ahead of the rest of the field in terms of the number of citations received in 1981–1999: in 1997–1999, the United States accounted for around 50 per cent of all citations. In the 1980s, the figure for the United States was still at around 55 per cent. Other top countries in a comparison of the share of citations in 1999 were the same as those at the top of the leaderboard in publication shares, although in a slightly different order: the United Kingdom (12.1%), Germany (10.7%), Japan (8.3%) and France (6.7%). During 1981–1999, the combined share of these biggest 'research countries' in world citations has shown some increase – that is despite of the decline of the share of the United States. It is noteworthy that with the exception of Japan, the biggest research countries have in recent years accounted for a considerably larger share of world citations than they have of publication production

6 It is possible that citations accrue unevenly to publications from different countries. Therefore the country citation shares that are calculated on the basis of the total counts may change in the future (see Table 4.8). A better way to compare citation counts is to look for instance at the development of the relative citation impact during a fixed period of time (see Table 4.10 and Figure 4.4).

Table 4.4. Number of scientific publications in OECD countries in 1981–1999.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Australia	10,833	10,761	10,961	11,047	11,651	12,278	12,130	12,332	13,087	13,303	14,046	15,199	15,612	17,058	18,428	19,017	19,533	20,561	21,125
Austria	2,780	2,754	2,810	2,694	3,044	3,123	3,143	3,168	3,538	3,664	3,813	4,302	4,395	4,749	5,403	5,531	6,161	6,476	6,718
Belgium	4,319	4,521	4,486	4,546	4,984	5,045	5,164	5,185	5,587	5,898	6,151	6,712	6,784	7,584	8,301	8,678	8,856	9,479	9,826
Canada	20,606	21,252	22,156	22,776	24,746	25,953	26,388	27,406	28,319	29,003	30,453	32,675	32,257	33,703	34,619	34,385	33,196	32,721	33,715
Czech Republic	0	0	0	0	0	0	0	0	0	0	0	0	0	3,213	3,238	3,660	3,580	3,864	3,887
Czechoslovakia	4,007	3,856	4,103	4,080	3,943	4,245	4,070	4,075	4,143	4,276	4,251	4,751	4,907	232	21	0	0	0	0
Denmark	3,895	3,981	3,974	3,884	4,132	4,469	4,354	4,322	4,655	4,730	4,951	5,717	5,625	6,260	6,476	6,659	6,839	7,460	7,453
Finland	2,635	2,948	3,158	3,208	3,283	3,434	3,625	3,558	3,784	3,986	4,245	4,712	4,923	5,475	5,759	6,126	6,410	6,632	6,980
France	23,607	24,126	24,163	24,152	25,866	28,048	27,839	29,032	30,376	31,234	32,838	36,464	36,479	39,696	41,865	43,090	44,440	46,595	47,447
Germany	34,288	35,462	35,546	34,816	38,007	38,979	39,244	39,928	42,068	43,259	45,333	48,453	47,391	51,498	54,468	56,627	59,873	63,917	64,379
Greece	983	1,102	1,160	1,164	1,281	1,522	1,644	1,730	2,011	1,935	2,286	2,566	2,595	3,120	3,285	3,626	3,823	4,284	4,349
Hungary	2,660	2,812	2,793	2,553	2,615	2,750	2,706	2,565	2,665	2,503	2,767	2,899	2,824	2,873	3,111	3,100	3,254	3,507	3,773
Iceland	46	84	74	57	84	88	87	101	108	146	179	187	198	205	257	266	262	312	291
Ireland	944	1,024	1,134	1,070	1,081	1,191	1,225	1,220	1,232	1,400	1,454	1,600	1,680	1,834	1,949	2,166	2,249	2,547	2,575
Italy	9,724	10,396	11,252	11,772	12,408	13,018	13,352	14,757	16,172	16,812	18,401	20,716	20,812	23,369	24,985	26,701	27,177	29,022	29,587
Japan	27,240	28,535	29,724	30,703	34,171	35,906	36,054	40,389	41,791	44,361	46,270	52,241	51,911	55,948	58,911	61,413	61,929	66,931	68,775
Korea	240	306	379	426	566	667	878	1,025	1,349	1,593	1,960	2,498	3,014	4,041	5,414	6,430	7,818	9,513	11,010
Mexico	931	976	1,013	983	1,133	1,262	1,308	1,312	1,451	1,547	1,667	2,045	2,236	2,541	2,949	3,326	3,623	4,088	4,553
Netherlands	7,370	7,523	8,284	8,756	9,520	9,998	10,164	10,828	12,014	12,715	13,045	14,678	14,955	16,087	16,983	17,379	18,087	18,355	18,314
New Zealand	2,286	2,368	2,419	2,393	2,439	2,432	2,426	2,722	2,558	2,859	2,826	3,055	3,019	3,449	3,624	3,879	3,978	4,297	4,312
Norway	2,349	2,532	2,587	2,520	2,798	2,730	2,751	2,813	2,827	3,079	3,167	3,662	3,594	3,904	4,338	4,369	4,505	4,728	4,847
Poland	4,645	3,699	4,532	4,643	4,851	5,040	4,927	5,323	5,765	5,473	5,624	6,086	5,826	6,345	7,157	7,312	7,219	7,856	8,406
Portugal	240	282	329	343	368	483	528	583	703	837	947	1,114	1,205	1,377	1,598	1,845	2,057	2,295	2,845
Spain	3,524	4,083	4,641	4,914	5,766	6,850	7,205	7,924	8,426	9,363	10,302	12,671	13,191	14,495	15,743	17,203	18,574	19,861	21,006
Sweden	6,932	7,581	7,779	8,044	8,704	9,016	8,927	9,268	9,886	10,080	10,282	10,983	11,400	12,157	12,890	13,637	13,756	14,444	14,753
Switzerland	6,239	6,420	6,780	6,500	7,201	7,311	7,410	7,570	7,712	8,210	8,991	10,062	10,367	11,301	11,661	11,868	12,670	13,150	13,729
Turkey	332	338	338	402	467	501	576	644	831	955	1,175	1,423	1,649	2,028	2,456	3,165	3,484	4,094	4,714
United Kingdom	40,056	41,170	42,363	41,417	45,045	46,049	45,774	45,938	46,856	48,523	50,801	55,374	55,291	60,279	63,819	65,823	64,498	67,701	69,220
United States	182,653	186,603	187,308	187,789	199,778	206,107	204,101	210,914	218,057	223,594	233,795	242,672	240,647	246,821	257,738	253,086	251,062	252,459	252,984
All countries	450,512	462,555	471,489	470,384	503,114	521,679	518,106	538,440	558,679	572,398	589,018	626,825	616,378	651,522	683,092	691,592	695,958	719,134	732,193

Source: Institute for Scientific Information, NSIOD 1981–1999.

Contents

Table 4.5. OECD countries’ shares of world scientific publications in 1981–1999 .

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Australia	2.40	2.33	2.32	2.35	2.32	2.35	2.34	2.29	2.34	2.32	2.38	2.42	2.53	2.62	2.70	2.75	2.81	2.86	2.89
Austria	0.62	0.60	0.60	0.57	0.61	0.60	0.61	0.59	0.63	0.64	0.65	0.69	0.71	0.73	0.79	0.80	0.89	0.90	0.92
Belgium	0.96	0.98	0.95	0.97	0.99	0.97	1.00	0.96	1.00	1.03	1.04	1.07	1.10	1.16	1.22	1.25	1.27	1.32	1.34
Canada	4.57	4.59	4.70	4.84	4.92	4.97	5.09	5.09	5.07	5.07	5.17	5.21	5.23	5.17	5.07	4.97	4.77	4.55	4.60
Czech Republic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.47	0.53	0.51	0.54	0.53
Denmark	0.86	0.86	0.84	0.83	0.82	0.86	0.84	0.80	0.83	0.83	0.84	0.91	0.91	0.96	0.95	0.96	0.98	1.04	1.02
Finland	0.58	0.64	0.67	0.68	0.65	0.66	0.70	0.66	0.68	0.70	0.72	0.75	0.80	0.84	0.84	0.89	0.92	0.92	0.95
France	5.24	5.22	5.12	5.13	5.14	5.38	5.37	5.39	5.44	5.46	5.58	5.82	5.92	6.09	6.13	6.23	6.39	6.48	6.48
Germany	7.61	7.67	7.54	7.40	7.55	7.47	7.57	7.42	7.53	7.56	7.70	7.73	7.69	7.90	7.97	8.19	8.60	8.89	8.79
Greece	0.22	0.24	0.25	0.25	0.25	0.29	0.32	0.32	0.36	0.34	0.39	0.41	0.42	0.48	0.48	0.52	0.55	0.60	0.59
Hungary	0.59	0.61	0.59	0.54	0.52	0.53	0.52	0.48	0.48	0.44	0.47	0.46	0.46	0.44	0.46	0.45	0.47	0.49	0.52
Iceland	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04
Ireland	0.21	0.22	0.24	0.23	0.21	0.23	0.24	0.23	0.22	0.24	0.25	0.26	0.27	0.28	0.29	0.31	0.32	0.35	0.35
Italy	2.16	2.25	2.39	2.50	2.47	2.50	2.58	2.74	2.89	2.94	3.12	3.30	3.38	3.59	3.66	3.86	3.90	4.04	4.04
Japan	6.05	6.17	6.30	6.53	6.79	6.88	6.96	7.50	7.48	7.75	7.86	8.33	8.42	8.59	8.62	8.88	8.90	9.31	9.39
Korea	0.05	0.07	0.08	0.09	0.11	0.13	0.17	0.19	0.24	0.28	0.33	0.40	0.49	0.62	0.79	0.93	1.12	1.32	1.50
Mexico	0.21	0.21	0.21	0.21	0.23	0.24	0.25	0.24	0.26	0.27	0.28	0.33	0.36	0.39	0.43	0.48	0.52	0.57	0.62
Netherlands	1.64	1.63	1.76	1.86	1.89	1.92	1.96	2.01	2.15	2.22	2.21	2.34	2.43	2.47	2.49	2.51	2.60	2.55	2.50
New Zealand	0.51	0.51	0.51	0.51	0.48	0.47	0.47	0.51	0.46	0.50	0.48	0.49	0.49	0.53	0.53	0.56	0.57	0.60	0.59
Norway	0.52	0.55	0.55	0.54	0.56	0.52	0.53	0.52	0.51	0.54	0.54	0.58	0.58	0.60	0.64	0.63	0.65	0.66	0.66
Poland	1.03	0.80	0.96	0.99	0.96	0.97	0.95	0.99	1.03	0.96	0.95	0.97	0.95	0.97	1.05	1.06	1.04	1.09	1.15
Portugal	0.05	0.06	0.07	0.07	0.07	0.09	0.10	0.11	0.13	0.15	0.16	0.18	0.20	0.21	0.23	0.27	0.30	0.32	0.39
Spain	0.78	0.88	0.98	1.04	1.15	1.31	1.39	1.47	1.51	1.64	1.75	2.02	2.14	2.22	2.30	2.49	2.67	2.76	2.87
Sweden	1.54	1.64	1.65	1.71	1.73	1.73	1.72	1.72	1.77	1.76	1.75	1.75	1.85	1.87	1.89	1.97	1.98	2.01	2.01
Switzerland	1.38	1.39	1.44	1.38	1.43	1.40	1.43	1.41	1.38	1.43	1.53	1.61	1.68	1.73	1.71	1.72	1.82	1.83	1.88
Turkey	0.07	0.07	0.07	0.09	0.09	0.10	0.11	0.12	0.15	0.17	0.20	0.23	0.27	0.31	0.36	0.46	0.50	0.57	0.64
United Kingdom	8.89	8.90	8.98	8.80	8.95	8.83	8.83	8.53	8.39	8.48	8.62	8.83	8.97	9.25	9.34	9.52	9.27	9.41	9.45
United States	40.54	40.34	39.73	39.92	39.71	39.51	39.39	39.17	39.03	39.06	39.69	38.71	39.04	37.88	37.73	36.59	36.07	35.11	34.55

Source: Institute for Scientific Information, NSIOD 1981–1999.

Table 4.6. Total growth of publication numbers in OECD countries and average annual growth rate in 1981–1989 and 1991–1999.

	1981	1989	% increase 1981–89	Average % increase per year	1991	1999	% increase 1991–99	Average % increase per year
Australia	10,833	13,087	20.8	2.39	14,046	21,125	50.4	5.23
Austria	2,780	3,538	27.3	3.06	3,813	6,718	76.2	7.34
Belgium	4,319	5,587	29.4	3.27	6,151	9,826	59.7	6.03
Canada	20,606	28,319	37.4	4.05	30,453	33,715	10.7	1.28
Denmark	3,895	4,655	19.5	2.25	4,951	7,453	50.5	5.25
Finland	2,635	3,784	43.6 (10th)	4.63	4,245	6,980	64.4 (9th)	6.41
France	23,607	30,376	28.7	3.20	32,838	47,447	44.5	4.71
Germany	34,288	42,068	22.7	2.59	45,333	64,379	42.0	4.48
Greece	983	2,011	104.6	9.36	2,286	4,349	90.2	8.37
Hungary	2,660	2,665	0.2	0.02	2,767	3,773	36.4	3.95
Iceland	46	108	34.8	1.26	179	291	62.6	6.26
Ireland	944	1,232	30.5	3.38	1,454	2,575	77.1	7.41
Italy	9,724	16,172	66.3	6.57	18,401	29,587	60.8	6.12
Japan	27,240	41,791	53.4	5.50	46,270	68,775	48.6	5.08
Korea	240	1,349	462.1	24.09	1,960	11,010	461.7	24.08
Mexico	931	1,451	55.9	5.70	1,667	4,553	173.1	13.38
Netherlands	7,370	12,014	63.0	6.30	13,045	18,314	40.4	4.33
New Zealand	2,286	2,558	11.9	1.42	2,826	4,312	52.6	5.42
Norway	2,349	2,827	20.3	2.34	3,167	4,847	53.0	5.46
Poland	4,645	5,765	24.1	2.74	5,624	8,406	49.5	5.15
Portugal	240	703	192.9	14.38	947	2,845	200.4	14.74
Spain	3,524	8,426	139.1	11.51	10,302	21,006	103.9	9.31
Sweden	6,932	9,886	42.6	4.54	10,282	14,753	43.5	4.62
Switzerland	6,239	7,712	23.6	2.68	8,991	13,729	52.7	5.43
Turkey	332	831	150.3	12.15	1,175	4,714	301.2	18.96
United Kingdom	40,056	46,856	17.0	1.98	50,801	69,220	36.3	3.94
United States	182,653	218,057	19.4	2.24	233,795	252,984	8.2	0.99
All countries	450,512	558,679	24.0	2.73	589,018	732,193	24.3	2.76

Source: Institute for Scientific Information, NSIOD 1981–1999.

Contents

Table 4.7. Number of citations received by scientific publications in OECD countries in 1981–1999.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Australia	169,286	166,263	177,216	170,549	182,035	184,990	175,150	186,812	176,214	165,935	168,074	169,744	163,672	153,470	137,979	105,348	72,129	37,258	7,044
Austria	26,210	29,288	30,112	29,095	33,151	35,687	38,134	38,064	47,403	44,654	46,917	53,271	50,609	45,146	43,056	33,664	26,746	12,691	2,292
Belgium	65,707	67,299	66,649	67,123	73,286	76,091	79,109	74,308	80,008	83,328	81,957	88,425	84,962	84,097	76,551	59,130	41,598	20,464	3,702
Canada	343,069	351,924	357,365	356,868	386,525	385,506	395,690	401,709	407,377	402,883	402,917	415,856	380,286	341,899	285,547	220,223	143,088	69,061	12,348
Czech Republic	0	0	0	0	0	0	0	0	0	0	0	0	0	15,653	14,159	12,058	8,427	4,375	823
Czechoslovakia	20,678	21,228	19,525	19,774	18,679	18,824	18,216	17,768	19,215	20,717	20,429	24,979	22,743	694	37	0	0	0	0
Denmark	80,907	81,777	78,064	75,288	78,984	82,653	79,027	74,879	76,425	82,758	81,729	81,214	82,313	74,415	64,236	46,954	34,677	18,051	3,075
Finland	40,090	43,177	47,844	45,538	50,310	45,946	54,176	55,351	50,561	53,355	58,552	63,005	64,685	61,839	53,312	41,434	30,158	13,470	2,357
France	317,498	322,099	327,114	338,605	362,325	377,257	386,547	396,061	397,367	411,034	425,336	431,185	416,788	391,253	339,378	266,064	186,832	92,409	15,303
Germany	438,103	446,639	466,419	449,973	491,204	496,460	524,867	508,938	543,453	564,196	552,771	565,318	557,697	521,321	460,626	374,051	267,042	137,849	24,274
Greece	8,535	8,968	10,053	10,542	10,766	11,945	13,714	12,517	15,160	15,255	15,744	17,498	16,841	17,018	16,710	14,421	9,669	4,970	825
Hungary	21,617	20,769	23,341	20,282	20,907	21,472	20,156	17,853	18,679	19,109	21,709	23,234	21,589	19,796	15,986	12,703	9,490	4,742	905
Iceland	684	1,248	1,343	1,396	1,068	1,669	1,891	1,596	1,982	2,030	2,100	2,581	3,601	2,215	2,995	1,662	1,303	602	193
Ireland	10,103	9,579	10,566	10,427	10,345	10,408	12,272	12,164	14,845	15,084	15,009	16,491	14,528	14,930	12,212	10,062	8,673	4,494	877
Italy	118,799	133,568	146,725	143,652	154,643	166,451	169,810	184,495	201,423	202,447	224,096	233,262	225,257	225,166	199,243	160,148	112,992	58,622	9,564
Japan	372,388	387,708	400,395	419,895	438,354	474,936	469,737	515,192	527,674	528,533	523,279	550,786	498,971	464,523	400,556	310,320	220,809	114,074	18,770
Korea	2,270	2,926	3,107	3,218	5,100	5,079	6,973	7,367	8,859	11,360	13,972	16,308	18,893	21,949	22,550	20,641	17,835	9,912	1,846
Mexico	9,471	9,734	9,253	9,062	10,761	10,350	11,042	10,664	12,687	12,347	11,696	14,904	14,547	13,982	14,006	11,435	8,632	4,357	841
Netherlands	144,092	141,503	157,412	169,011	177,916	174,311	184,780	195,792	201,725	211,208	211,423	215,183	209,090	192,446	171,222	126,907	93,651	43,961	7,536
New Zealand	26,284	26,961	28,015	29,923	31,406	30,153	32,781	32,437	30,744	35,011	29,200	32,286	29,961	27,101	24,507	19,369	13,302	6,566	1,186
Norway	34,813	40,122	38,258	36,274	40,485	39,290	38,240	38,865	38,481	40,343	38,522	42,321	38,850	35,892	33,515	22,889	17,836	9,046	1,606
Poland	34,333	27,275	31,955	29,530	30,348	33,630	33,146	35,184	36,226	34,751	37,886	37,266	33,977	34,519	33,042	25,006	17,283	9,060	1,896
Portugal	2,394	3,810	3,716	3,870	3,594	5,558	4,856	5,019	6,024	7,663	8,050	10,304	9,556	10,134	9,287	7,607	6,060	3,257	1,011
Spain	26,915	31,395	33,538	40,701	47,717	57,969	59,265	68,915	75,899	87,597	92,987	113,279	116,120	114,433	99,722	87,431	62,929	32,429	5,763
Sweden	158,662	164,846	174,429	176,413	188,674	184,816	170,240	176,687	180,279	177,261	174,566	169,857	161,226	147,498	125,358	98,642	67,092	32,075	5,195
Switzerland	135,754	148,305	151,046	145,439	160,925	162,024	160,948	172,717	162,798	167,205	176,078	178,046	175,013	171,751	140,790	111,086	84,056	40,018	7,220
Turkey	2,548	2,270	2,205	2,843	3,035	3,084	3,897	3,994	4,878	4,653	5,726	7,255	7,606	8,135	8,171	7,373	5,327	2,668	442
United Kingdom	736,354	739,547	759,476	764,773	772,836	778,392	774,411	743,533	746,451	789,526	755,581	776,729	728,654	664,934	580,665	437,151	306,777	151,813	27,368
United States	3,928,209	3,907,079	4,002,833	4,036,698	4,218,579	4,239,051	4,313,792	4,304,648	4,282,578	4,260,984	4,131,220	3,982,170	3,659,383	3,243,487	2,753,199	2,036,932	1,358,682	651,375	114,794
All Countries*	7,064,028	7,063,215	7,232,641	7,239,210	7,586,959	7,642,597	7,704,236	7,721,230	7,748,878	7,755,993	7,509,980	7,377,730	6,841,796	6,137,337	5,259,808	3,955,906	2,700,317	1,308,824	226,980

* No combined numbers of citations of all countries was not available from NSIOD. The number of citations was calculated by multiplying the world impact base figure by the number of publications each year under review.

Source: Institute for Scientific Information, NSIOD 1981-1999.

Table 4.8. Citations received by scientific publications in OECD countries as a proportion (%) of world citations in 1981–1999.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Australia	2.40	2.35	2.45	2.36	2.40	2.42	2.27	2.42	2.27	2.14	2.24	2.30	2.39	2.50	2.62	2.66	2.67	2.85	3.10
Austria	0.37	0.41	0.42	0.40	0.44	0.47	0.49	0.49	0.61	0.58	0.62	0.72	0.74	0.74	0.82	0.85	0.99	0.97	1.01
Belgium	0.93	0.95	0.92	0.93	0.97	1.00	1.03	0.96	1.03	1.07	1.09	1.20	1.24	1.37	1.46	1.49	1.54	1.56	1.63
Canada	4.86	4.98	4.94	4.93	5.09	5.04	5.14	5.20	5.26	5.19	5.37	5.64	5.56	5.57	5.43	5.57	5.30	5.28	5.44
Czech Republic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.27	0.30	0.31	0.33	0.36
Denmark	1.15	1.16	1.08	1.04	1.04	1.08	1.03	0.97	0.99	1.07	1.09	1.10	1.20	1.21	1.22	1.19	1.28	1.38	1.35
Finland	0.57	0.61	0.66	0.63	0.66	0.60	0.70	0.72	0.65	0.69	0.78	0.85	0.95	1.01	1.01	1.05	1.12	1.03	1.04
France	4.49	4.56	4.52	4.68	4.78	4.94	5.02	5.13	5.13	5.30	5.66	5.84	6.09	6.37	6.45	6.73	6.92	7.06	6.74
Germany	6.20	6.32	6.45	6.22	6.47	6.50	6.18	6.59	7.01	7.27	7.36	7.66	8.15	8.49	8.76	9.46	9.89	10.53	10.69
Greece	0.12	0.13	0.14	0.15	0.14	0.16	0.18	0.16	0.20	0.20	0.21	0.24	0.25	0.28	0.32	0.36	0.36	0.38	0.36
Hungary	0.31	0.29	0.32	0.28	0.28	0.28	0.26	0.23	0.24	0.25	0.29	0.31	0.32	0.32	0.30	0.32	0.35	0.36	0.40
Iceland	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.05	0.04	0.06	0.04	0.05	0.05	0.09
Irealand	0.14	0.14	0.15	0.14	0.14	0.14	0.16	0.16	0.19	0.19	0.20	0.22	0.21	0.24	0.23	0.25	0.32	0.34	0.39
Italy	1.68	1.89	2.03	1.98	2.04	2.18	2.20	2.39	2.60	2.61	2.98	3.16	3.29	3.67	3.79	4.05	4.18	4.48	4.21
Japan	5.27	5.49	5.54	5.80	5.78	6.21	6.10	6.67	6.81	6.81	6.97	7.47	7.29	7.57	7.62	7.84	8.18	8.72	8.27
Korea	0.03	0.04	0.04	0.04	0.07	0.07	0.09	0.10	0.11	0.15	0.19	0.22	0.28	0.36	0.43	0.52	0.66	0.76	0.81
Mexico	0.13	0.14	0.13	0.13	0.14	0.14	0.14	0.14	0.16	0.16	0.16	0.20	0.21	0.23	0.27	0.29	0.32	0.33	0.37
Netherlands	2.04	2.00	2.18	2.33	2.35	2.28	2.40	2.54	2.60	2.72	2.82	2.92	3.06	3.14	3.26	3.21	3.47	3.36	3.32
New Zealand	0.37	0.38	0.39	0.41	0.41	0.39	0.43	0.42	0.40	0.45	0.39	0.44	0.44	0.44	0.47	0.49	0.49	0.50	0.52
Norway	0.49	0.57	0.53	0.50	0.53	0.51	0.50	0.50	0.50	0.52	0.51	0.57	0.57	0.58	0.64	0.58	0.66	0.69	0.71
Poland	0.49	0.39	0.44	0.41	0.40	0.44	0.43	0.46	0.47	0.45	0.50	0.51	0.50	0.56	0.63	0.63	0.64	0.69	0.84
Portugal	0.03	0.05	0.05	0.05	0.05	0.07	0.06	0.07	0.08	0.10	0.11	0.14	0.14	0.17	0.18	0.19	0.22	0.25	0.45
Spain	0.38	0.44	0.46	0.56	0.63	0.76	0.77	0.89	0.98	1.13	1.24	1.54	1.70	1.86	1.90	2.21	2.33	2.48	2.54
Sweden	2.25	2.33	2.41	2.44	2.49	2.42	2.21	2.29	2.33	2.29	2.32	2.30	2.36	2.40	2.38	2.49	2.48	2.45	2.29
Switzerland	1.92	2.10	2.09	2.01	2.12	2.12	2.09	2.24	2.10	2.16	2.34	2.41	2.56	2.80	2.68	2.81	3.11	3.06	3.18
Turkey	0.04	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.06	0.06	0.08	0.10	0.11	0.13	0.16	0.19	0.20	0.20	0.19
United Kingdom	10.42	10.47	10.50	10.56	10.19	10.18	10.05	9.63	9.63	10.18	10.06	10.53	10.65	10.83	11.04	11.05	11.36	11.60	12.06
United States	55.61	55.32	55.34	55.76	55.60	55.47	55.99	55.75	55.27	54.94	55.01	53.98	53.49	52.85	52.34	51.49	50.32	49.77	50.57

Source: Institute for Scientific Information, NSIOD 1981–1999.

volumes (cf. Table 4.5, see also Figure 4.5). So, at the same time as the 'biggest countries' have succeeded in maintaining their key position with respect to publishing activity, the international visibility and impact of research in these countries has increased (with the exception of the United States).

In the 1990s, the share of world citations increased most in Germany (by over 3 percentage points) and in the United Kingdom (about 2 percentage points). Citations received by Finnish publications as a proportion of world citations started to increase significantly from 1991 onwards (Table 4.8). At that time, Finland's share of all citations increased from 0.69 in the previous year to 0.78 per cent. From the same year onwards, Finland's share of world citations has been higher than its share of world publications. From 1994 onwards, the citation share of Finland has been over one per cent. Finland's share of world citations was 15th highest in the OECD group throughout the 1990s.

Figure 4.3 shows how the OECD countries' shares of world publications and citations have developed in the 1990s. The Figure indicates for each country the percentage change of these shares between 1990–1992 and 1997–1999. In the countries above the regression line, the increase in the proportion of citations has on average been faster, in the countries below the line the increase has been slower than might be assumed on the basis of the change in publication shares and compared to other countries.

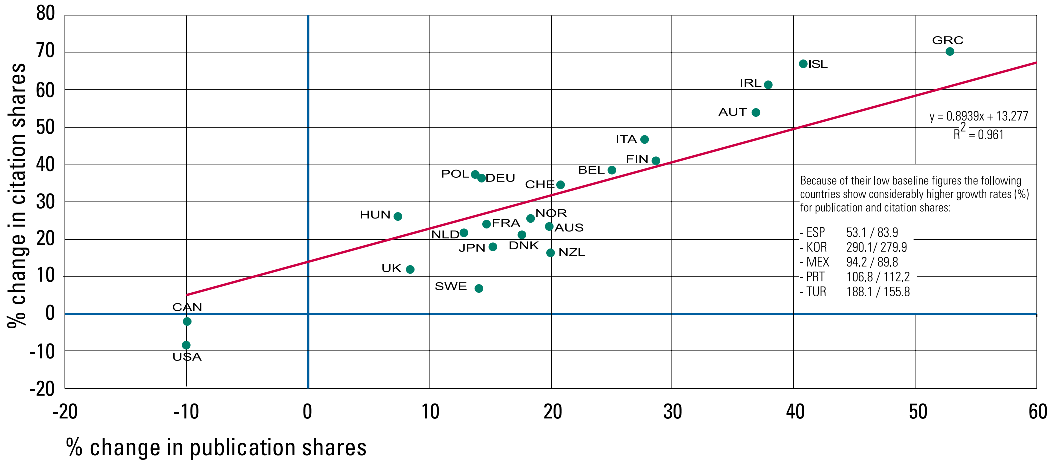
There are quite marked differences in the trends for publication and citation shares in different OECD countries. Finland belongs (although barely) to the group of countries where the relative increase in the citation share has on average been faster than might be assumed on the basis of the development of publication shares and in comparison with the other countries (location above the regression line). Other countries in this group include Germany, Switzerland, Poland, Italy and Belgium. In another words, international visibility and impact of scientific research of these countries have developed relatively more favourably compared to international publishing activity. The situation is the opposite for instance in France, the Netherlands, Denmark, Japan, the United Kingdom and Sweden. In these countries, the relative increase in the citation share has on average been slower than might be assumed on the basis of the development of the publication share and in comparison with the other countries.

Among the countries with a high R&D intensity, the publication share has shown comparatively slow growth during the 1990s in the United Kingdom, Japan and Sweden. In Sweden, the relative development of the citation share has also been rather slow. Canada and the United States are the only OECD countries whose shares of publications and citations in the world have declined during the period under review.

Number of publications relative to GDP, R&D expenditure and population

Table 4.9 compares the number of publications in OECD countries to GDP, R&D expenditure in universities and research institutes and total population. The publication data are for 1999, the other data for 1997. On the basis of these figures Finland produced the third highest number of publications relative to GDP, after

Figure 4.3. OECD countries' shares of world publications and citations: percentage change of share from period 1990–1992 to period 1997–1999. For example, Finland's share of world publications was 0.72 per cent in 1990–1992 and 0.93 per cent in 1997–1999, i.e. the share increased by 29 per cent. At the same time, the share of citations increased by some 41 per cent (from 0.77% to 1.09%).



Sweden and Switzerland. When the number of publications is examined in relation to universities' and research institutes' R&D expenditures, Finland ranks 12th. The top three countries in this analysis are Hungary, Switzerland and New Zealand. Relative to population, Finland ranks fourth after Switzerland, Sweden and Denmark.

The indicators in Table 4.9 provide only rather crude instruments for an interpretation of country differences in science systems. In principle, they might reflect differences in the efficiency of science systems, but we can draw no definitive conclusions. The ratio of the number of publications to GDP provides an indication primarily of the level of academic research aimed at international visibility and its position in relation to the wealth of the nation. An interesting observation for both Finland and some other countries is that the economic recession of the 1990s and the decrease in GDP had no impact on the number of publications published. Measured in terms of publication numbers, research output was high in spite of the cutbacks in university resources that followed with the recession[7]. The publication number per capita, then, provides an indication of the output and respect enjoyed by research relative to the size of the population. Accordingly, the figures relative to universities' and research institutes' R&D expenditures give a rough idea of the efficiency of these institutions in different countries. However, it is important to remember that the number of publications provides just one angle on scientific work. University research in different countries may have different goals and objectives, and not all research is aimed primarily at high international visibility.

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7 There may be several possible reasons for this. For instance, it is possible that the cutbacks necessitated by the recession in university funding were not so dramatic as to have caused any immediate or irreparable damage to the structures of research. However, that does not necessarily mean there were no adverse effects on the development of basic university functions (basic education, postgraduate education, adult education, research, outside collaboration) that can be attributed to the declining economy. The overall impacts of the decrease in university resources are not necessarily immediately visible in bibliometric indicators of research output and impact.

Table 4.9. Number of scientific publications in OECD countries relative to GDP, universities' and research institutes' R&D expenditures and population.

Number of publications 1999/GDP (US$ bill.)			Number of publications 1999/R&D expenditure in universities and research institutes (US$ mill.) in 1997			Number of publications in 1999/10,000 inhabitants in 1997		
1.	Sweden	81.6	1.	Hungary	107.2	1.	Switzerland	19.3
2.	Switzerland	74.5	2.	Switzerland	105.0	2.	Sweden	16.7
3.	Finland	66.3	3.	New Zealand	97.6	3.	Denmark	14.1
4.	New Zealand	64.1	4.	Greece	96.0	4.	Finland	13.6
5.	Denmark	58.2	5.	Ireland	93.0	5.	Netherlands	11.7
6.	United Kingdom	57.4	6.	Belgium	91.5	6.	United Kingdom	11.7
7.	Netherlands	53.0	7.	United Kingdom	91.5	7.	New Zealand	11.5
8.	Australia	50.4	8.	Sweden	84.4	8.	Australia	11.4
9.	Canada	46.9	9.	Canada	82.6	9.	Canada	11.1
10.	Iceland	43.2	10.	Denmark	78.9	10.	Norway	11.0
11.	Belgium	41.6	11.	Spain	77.4	11.	Iceland	10.7
12.	Norway	41.1	12.	Finland	76.3	12.	Belgium	9.7
13.	France	38.0	13.	Czech Republic	68.1	13.	United States	9.5
14.	Hungary	37.6	14.	Austria	67.2	14.	Austria	8.3
15.	Austria	36.0	15.	Poland	63.6	15.	France	8.1
16.	Germany	35.5	16.	Australia	62.4	16.	Germany	7.8
17.	Ireland	34.4	17.	Netherlands	57.6	17.	Ireland	7.0
18.	Spain	33.4	18.	Norway	56.9	18.	Japan	5.5
19.	United States	32.3	19.	United States	52.8	19.	Spain	5.3
20.	Greece	29.7	20.	Italy	48.2	20.	Italy	5.1
21.	Poland	29.1	21.	Germany	46.8	21.	Greece	4.1
22.	Czech Republic	28.7	22.	Portugal	46.5	22.	Czech Republic	3.8
23.	Italy	24.2	23.	France	45.8	23.	Hungary	3.7
24.	Japan	22.2	24.	Iceland	45.5	24.	Portugal	2.9
25.	Portugal	19.7	25.	Turkey	37.5	25.	Korea	2.4
26.	Korea	16.5	26.	Japan	33.0	26.	Poland	2.2
27.	Turkey	11.4	27.	Mexico	30.2	27.	Turkey	0.7
28.	Mexico	6.3	28.	Korea	21.8	28.	Mexico	0.5

Source: Institute for Scientific Information, NSIOD 1981–1999; OECD, Main Science and Technology Indicators.

Impact factors and relative citation impacts

Impact factor and the relative citation impacts (or indices) are indicators that describe the visibility and impact of research. The results of OECD comparisons are shown in Figures 4.4 and 4.5 and in Tables 4.10 and 4.11. Both Figures reflect the same finding in the sense that the rank-orders of the countries are unchanged in them. The same applies to the two Tables. However, the point of view differs both between the Figures and the Tables. Generally, the impact factor indicates how many citations the publications of each country have received on average each year. In contrast, the relative citation impact indicates (in percentage terms) the number of citations per publication for a given country compared to the number of citations per publication for all the countries (world average = 1).

Figures 4.4 and 4.5 show the trends for impact factors and relative citation impacts in the top 12 OECD countries in overlapping five-year periods (from 1981–1985 to 1995–1999)[8]. The impact factor has increased rather steadily during the period under review. In the early 1980s, the average number of world citations per publication was 2.7, by 1995–1999 the figure had increased to 3.8 citations. In 1988–1992, there were only seven OECD countries where the impact factor was higher than the world average (i.e. where the impact value was over 1). At that time Finland, France, Germany, Iceland and Canada were still below the average. Since 1991–1995, all the top countries have been above the world average. For most of the period under review Switzerland and the United States have recorded clearly higher impact factors than others.

Moving on to examine the trends for the relative citation impact, we find that there has been a marked increase in the impact from the 1980s through to the 1990s in Finland, Canada, Germany, France and Belgium and to some extent also in the United States. In other countries, the impact value has remained more or less unchanged (e.g. the United Kingdom) or declined (e.g. Sweden). During 1995–1999, the impact factor (4.41) and relative citation impact (1.15) for Finland were ninth highest in the OECD group.

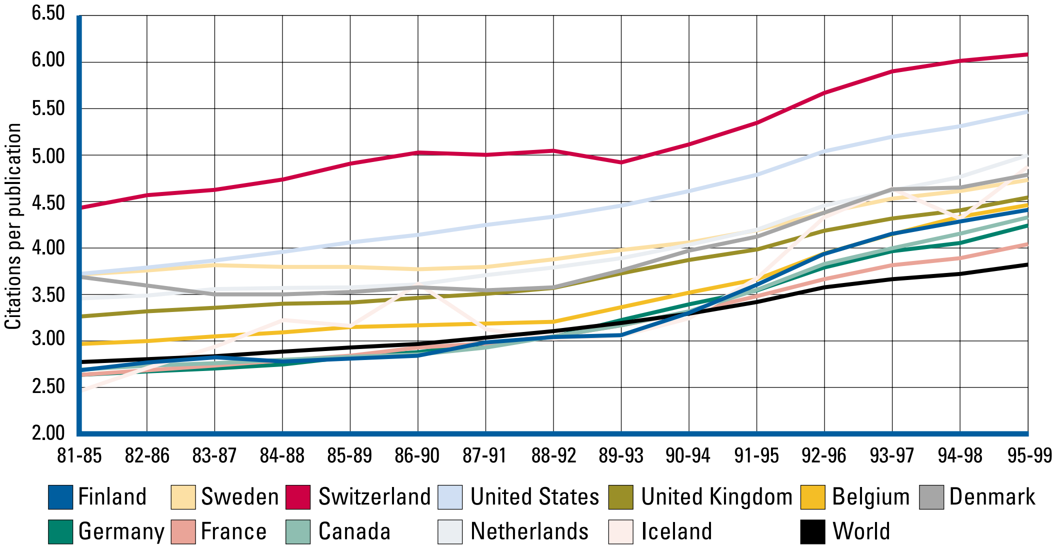
Tables 4.10 and 4.11 describe the impact factors and relative citation impacts for the OECD countries in rank order by different fields of science. The indicators describe the situation in 1995–1999. These indicators point at quite considerable differences between the different fields. However, it needs to be remembered that impact factors and indices should not be used for quality comparisons between different disciplines. The number of citations is highest in the medical sciences (on average 4.8 citations/publication) and in the natural sciences (4.3). The lowest figure is recorded in the humanities (0.3).

The countries that come out on top in the comparison of different fields of science are the United States, the Netherlands, Switzerland (with the exception of the humanities and the social sciences) and the United Kingdom (with the exception of engineering and technology). Sweden, Canada, Iceland, Finland, Belgium and Denmark also fare reasonably well in several fields of science.

Although Finland accounts for a relatively small proportion of world publications and citations, we still rank reasonably high in an OECD comparison of impact factors and

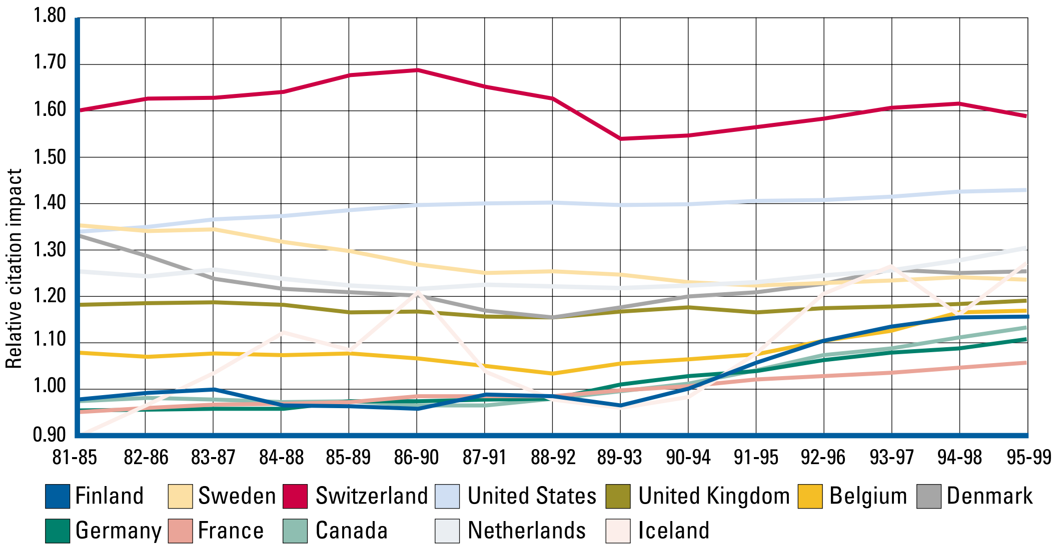
8 The citation figures on which the indices are based only include the citations accrued during the years concerned. For this reason the citation frequencies differ from the total numbers indicated in Table 4.7.

Figure 4.4. Development of impact factor for the top 12 OECD countries from 1981–1985 to 1995–1999.



Source: Institute for Scientific Information, NSIOD 1981–1999.

Figure 4.5. Development of relative citation impact for the top 12 OECD countries from 1981–1985 to 1995–1999.



Source: Institute for Scientific Information, NSIOD 1981–1999.

citation indices. According to these comparisons, the most successful field of science in Finland in 1995–1999 was the agricultural sciences, ranking fifth (at the same time, Finland's share of world publications in this field was 16th highest in the OECD group). The impact factor and relative citation impact for the medical sciences were eighth highest. All other fields – natural sciences, humanities, social sciences, and engineering and technology – ranked 10th–11th in this comparison.

Table 4.10. OECD countries' impact factors by field of science in 1995–1999.

	Natural sciences		Engineering and technology		Medical sciences		Agricultural sciences		Social sciences		Humanities	
1.	Switzerland	6.72	Switzerland	2.59	Iceland	7.04	Netherlands	2.80	United States	2.13	Iceland	0.60
2.	United States	6.66	Denmark	2.06	Unites States	6.49	Denmark	2.70	Canada	1.84	Greece	0.45
3.	Netherlands	5.47	United States	2.03	Switzerland	6.12	Switzerland	2.69	Netherlands	1.82	New Zealand	0.39
4.	United Kingdom	5.42	Netherlands	1.95	Netherlands	5.85	United Kingdom	2.66	Italy	1.68	Australia	0.38
5.	Denmark	5.18	Sweden	1.89	Canada	5.81	Finland	2.56	United Kingdom	1.67	United Kingdom	0.36
6.	Sweden	5.08	France	1.86	Belgium	5.48	Sweden	2.48	New Zealand	1.66	United States	0.36
7.	Germany	4.88	Belgium	1.85	United Kingdom	5.47	United States	2.47	Sweden	1.64	Turkey	0.34
8.	Canada	4.85	Germany	1.80	Finland	5.35	France	2.37	Iceland	1.63	Netherlands	0.34
9.	Iceland	4.82	Austria	1.79	Sweden	5.30	Norway	2.35	Belgium	1.58	Sweden	0.26
10.	Belgium	4.66	Finland	1.70	Denmark	5.27	Iceland	2.32	Finland	1.54	Canada	0.25
11.	Finland	4.65	Canada	1.68	New Zealand	4.99	Ireland	2.28	Norway	1.49	Finland	0.25
12.	Austria	4.36	Norway	1.67	Australia	4.72	Canada	2.28	Switzerland	1.43	Belgium	0.25
13.	France	4.35	Spain	1.66	Italy	4.72	Belgium	2.24	Australia	1.38	Japan	0.25
14.	Australia	4.14	Italy	1.66	France	4.63	Australia	2.13	France	1.37	Denmark	0.24
15.	Italy	3.99	Australia	1.63	Norway	4.62	Spain	2.04	Austria	1.35	Ireland	0.21
16.	Norway	3.87	United Kingdom	1.61	Ireland	4.37	New Zealand	2.00	Germany	1.33	Germany	0.20
17.	Japan	3.65	Japan	1.43	Germany	4.35	Japan	1.79	Spain	1.29	Italy	0.20
18.	Ireland	3.48	Hungary	1.40	Austria	4.29	Italy	1.74	Hungary	1.19	Hungary	0.20
19.	Spain	3.42	New Zealand	1.37	Portugal	3.66	Germany	1.73	Denmark	1.18	Norway	0.18
20.	New Zealand	3.38	Ireland	1.26	Japan	3.65	Portugal	1.59	Ireland	1.10	Mexico	0.17
21.	Greece	2.77	Portugal	1.26	Spain	3.39	Mexico	1.53	Portugal	1.07	Austria	0.15
22.	Portugal	2.73	Greece	1.14	Hungary	3.24	Korea	1.49	Korea	0.98	Switzerland	0.13
23.	Hungary	2.72	Poland	1.12	Poland	2.90	Austria	1.47	Japan	0.97	France	0.12
24.	Poland	2.37	Iceland	1.09	Greece	2.76	Greece	1.39	Poland	0.88	Portugal	0.12
25.	Mexico	2.33	Mexico	1.07	Mexico	2.50	Poland	1.25	Turkey	0.84	Spain	0.10
26.	Korea	2.03	Korea	1.03	Korea	2.34	Turkey	1.15	Greece	0.77	Korea	0.09
27.	Turkey	1.64	Turkey	0.87	Turkey	1.22	Hungary	0.86	Mexico	0.77	Poland	0.08
All countries average		4.294		1.529		4.773		1.891		1.783		0.287

* Impact factor = number of citations to publications in the field by country concerned / number of publications in the field by country. E.g. Finland's citation impact in natural sciences in 1995–1999 is 4.652, i.e. 72,427 citations / 15,569 publications.

Source: Institute for Scientific Information, NSIOD 1981–1999.

Contents

Table 4.11. OECD countries' relative citation impact by field of science in 1995–1999.

	Natural sciences		Engineering and technology		Medical sciences		Agricultural sciences		Social sciences		Humanities	
1.	Switzerland	1.56	Switzerland	1.69	Iceland	1.47	Netherlands	1.48	United States	1.19	Iceland	2.09
2.	United States	1.55	Denmark	1.35	United States	1.36	Denmark	1.43	Canada	1.03	Greece	1.58
3.	Netherlands	1.28	United States	1.33	Switzerland	1.28	Switzerland	1.42	Netherlands	1.02	New Zealand	1.36
4.	United Kingdom	1.26	Netherlands	1.27	Netherlands	1.23	United Kingdom	1.41	Italy	0.94	Australia	1.32
5.	Denmark	1.21	Sweden	1.24	Canada	1.22	Finland	1.35	United Kingdom	0.94	United Kingdom	1.26
6.	Sweden	1.18	France	1.22	Belgium	1.15	Sweden	1.31	New Zealand	0.93	United States	1.24
7.	Germany	1.14	Belgium	1.21	United Kingdom	1.15	United States	1.31	Sweden	0.92	Turkey	1.19
8.	Canada	1.13	Germany	1.18	Finland	1.12	France	1.25	Iceland	0.91	Netherlands	1.17
9.	Iceland	1.12	Austria	1.17	Sweden	1.11	Norway	1.24	Belgium	0.89	Sweden	0.90
10.	Belgium	1.09	Finland	1.11	Denmark	1.10	Iceland	1.23	Finland	0.86	Canada	0.88
11.	Finland	1.08	Canada	1.10	New Zealand	1.05	Ireland	1.20	Norway	0.83	Finland	0.88
12.	Austria	1.01	Norway	1.09	Australia	0.99	Canada	1.20	Switzerland	0.80	Belgium	0.87
13.	France	1.01	Spain	1.08	Italy	0.99	Belgium	1.18	Australia	0.77	Japan	0.86
14.	Australia	0.96	Italy	1.08	France	0.97	Australia	1.12	France	0.77	Denmark	0.82
15.	Italy	0.93	Australia	1.06	Norway	0.97	Spain	1.08	Austria	0.76	Ireland	0.72
16.	Norway	0.90	United Kingdom	1.05	Ireland	0.92	New Zealand	1.06	Germany	0.75	Germany	0.70
17.	Japan	0.85	Japan	0.94	Germany	0.91	Japan	0.95	Spain	0.72	Italy	0.69
18.	Ireland	0.81	Hungary	0.92	Austria	0.90	Italy	0.92	Hungary	0.67	Hungary	0.69
19.	Spain	0.80	New Zealand	0.90	Portugal	0.77	Germany	0.92	Denmark	0.66	Norway	0.64
20.	New Zealand	0.79	Ireland	0.82	Japan	0.76	Portugal	0.84	Ireland	0.61	Mexico	0.59
21.	Greece	0.65	Portugal	0.82	Spain	0.71	Mexico	0.81	Portugal	0.60	Austria	0.52
22.	Portugal	0.64	Greece	0.75	Hungary	0.68	Korea	0.79	Korea	0.55	Switzerland	0.44
23.	Hungary	0.63	Poland	0.73	Poland	0.61	Austria	0.78	Japan	0.55	France	0.41
24.	Poland	0.55	Iceland	0.71	Greece	0.58	Greece	0.73	Poland	0.50	Portugal	0.40
25.	Mexico	0.54	Mexico	0.70	Mexico	0.52	Poland	0.66	Turkey	0.47	Spain	0.34
26.	Korea	0.47	Korea	0.67	Korea	0.49	Turkey	0.61	Greece	0.43	Korea	0.33
27.	Turkey	0.38	Turkey	0.57	Turkey	0.26	Hungary	0.46	Mexico	0.43	Poland	0.29

* Relative citation impact = the number of citations to all publications in the field by country concerned / the total number of citations to the world publications in the field. E.g. Finland's relative citation impact in natural sciences in 1995–1999 is obtained as follows: (72,427 citations / 15,569 publications = 4.652) / (8,049,885 citations / 1,874,886 publications = 4.294) = 1.08

Source: Institute for Scientific Information, NSIOD 1981–1999.

In an analysis of the OECD countries' publication profiles we find that the Nordic countries differ quite clearly from most other countries (see Table 4.12). In particular, Finland and Sweden clearly stand apart from the rest of the field with rather similar profiles. In these countries, the natural sciences account for a relatively small proportion of all publications: in Finland, the share of the natural sciences (44%) is fourth lowest in the OECD group after Turkey, the United States and Ireland (world average 49%). The shares for the humanities, and engineering and technology are also clearly below the average. In the agricultural sciences and in the social sciences Finland's share is around the average for the OECD countries. The share of the medical sciences, on the other hand, is very high in Finland, as it is in the other Nordic countries: the figure for Finland (41%) is the third highest in the OECD group (world average 30%).

In 1997–1999, the top three countries in terms of the number of natural science publications as a proportion of total publications in the country were Poland (75%), the Czech Republic and Hungary. The highest proportion for the medical sciences was recorded in Turkey (43%), Iceland and Finland. As regards engineering and technology, the list was headed by Korea (23.4%), Greece and Portugal. The figure for the social sciences was highest in the United States (11%), for the humanities in Canada (3.3%) and for the agricultural sciences in New Zealand (6.3%).

Summary

Relative science indicators based on publication and citation analysis indicate that on average, Finland ranks 5th–10th in the OECD group. The situation is obviously entirely different in an analysis based on absolute numbers. For instance, in 1999, the total number of scientific publications in Finland (6,980) was 17th highest in the OECD, in terms of university and research institute R&D expenditure Finland ranked 18th. Relative to population and GDP, however, Finland ranks among the biggest publishers in the world: on the basis of these indicators we rank among the top four countries in the world. When the number of publications is related to universities' and research institutes' R&D expenditure, Finland ranks 12th.

Judged on the basis of a cluster of several relative publication and citation indicators[9], the top OECD research nations are Switzerland, Sweden and the Netherlands. Although there are indicators where the scores for the United States are not particularly high[10], it certainly deserves a place in this top group by virtue of its level of publishing and the visibility and impact of its research The next group comprises Denmark, the United Kingdom, Belgium, Finland and Iceland as well as Germany, Canada and France. There is no point trying to rank-order these countries in any greater detail than this; the outcome may vary considerably depending on the indicators and the approach adopted (absolute vs. relative figures; development trends) and the period analysed.

9 Number of scientific publications, number of citations received by these publications, trends for both the former, number of scientific publications relative to GDP, research expenditure and population, level and trends of impact factors and relative citation indices.

10 For instance, the development of publication and citation numbers and the number of scientific publications relative to GDP, research expenditure or population.

Table 4.12. Breakdown of scientific publications in OECD countries by major field of science in 1997–1999. The figures indicate the number of publications in each field as a percentage of each country's total publications.

	Natural sciences	Medical sciences	Agricultural sciences	Engineering and technology	Social sciences	Humanities
Australia	48.4	28.8	3.1	7.8	9.7	2.3
Austria	47.3	40.0	1.4	6.9	2.7	1.6
Belgium	51.5	33.4	1.9	7.6	3.9	1.7
Canada	46.9	29.4	2.1	9.0	9.4	3.3
Czech Republic	71.2	10.7	3.1	10.1	3.1	1.9
Denmark	53.4	34.7	2.8	5.4	2.9	0.8
Finland	44.1 (25th highest)	40.9 (3rd)	2.3 (13th)	6.9 (23rd)	5.0 (10th)	0.8 (21st)
France	57.3	27.9	1.7	8.6	2.1	2.4
Germany	55.8	29.2	1.7	8.7	2.8	1.8
Greece	50.4	27.9	2.8	14.8	3.1	1.0
Hungary	66.1	20.3	3.7	7.2	1.7	1.1
Iceland	45.2	41.2	2.0	3.0	6.8	1.7
Ireland	43.4	33.2	5.8	7.9	6.6	3.2
Italy	51.4	35.2	1.8	8.9	1.8	0.9
Japan	55.8	28.1	2.4	12.5	1.0	0.1
Korea	58.5	15.0	1.1	23.4	1.9	0.1
Mexico	63.4	19.4	3.5	8.4	3.9	1.4
Netherlands	46.3	36.3	2.2	6.5	7.3	1.4
New Zealand	49.4	26.4	6.3	5.8	9.6	2.4
Norway	49.2	34.3	2.1	6.0	7.2	1.2
Poland	75.0	12.1	1.5	9.9	0.9	0.6
Portugal	62.2	16.6	3.9	14.6	2.0	0.8
Spain	58.4	26.3	3.6	7.2	2.6	2.0
Sweden	45.5	40.1	1.4	8.2	4.4	0.6
Switzerland	54.7	33.4	1.3	7.2	2.3	1.1
Turkey	38.5	42.9	2.5	13.2	2.6	0.4
United Kingdom	45.0	32.6	1.5	8.5	9.2	3.1
United States	43.3	32.4	1.5	8.4	11.3	3.1
All countries	49.2	29.6	2.1	10.0	6.8	2.3

Source: Institute for Scientific Information, NSIOD 1981–1999.

4.4 Impact of research

4.4.1 Transmission of research impacts in the innovation process

The role and significance of research in the innovation process is traditionally examined on the basis of the linear innovation model. This model has it that basic research precedes applied research and the development work that follows. Basic research is considered chiefly as a source of technological development and as a factor that regulates the prospects of achieving innovations. This is somewhat misleading and puts basic research in a rather awkward position – on the one hand the view overestimates the role and direct impact of scientific research in technological change and on the other hand underestimates the complex indirect effects of basic research. Indeed, views on the innovation process began to change in the 1990s. There was now a growing recognition of the role of collaboration and learning as preconditions for innovation, and the whole process was understood as a set of functions interlinked through complex feedback loops (see e.g. Kline & Rosenberg 1986; Lundvall 1992; Mowery 1995; David & Foray 1996; Husso & Kangaspunta 1999).

The growth of scientific knowledge promotes innovation by lowering the costs of research and development to individual business companies. Given a sound and solid scientific foundation, companies can proceed to identify and define their R&D options and focus their attention on the most feasible technological approaches. Basic research provides reliable information on potential areas of applications, and above all on areas where the search for applications is unlikely to yield results (e.g. Rosenberg 1974; Nelson 1982; Pavitt 1991; David 1997). In the long term, scientific knowledge and the methods and tools of basic research have a decisive impact on research productivity and the profitability of investing in research. In addition, the development of scientific and technological knowledge is a cumulative process that in the long term depends on the publication of new discoveries. Public support for research and internationalisation is essential because business companies themselves do not have a very strong academic interest to publish and disseminate their results.

The benefits and external impacts of research will be considerably lesser and the dissemination of know-how will be constrained if the benefits are restricted to whoever is doing the research or who has commissioned the research. On the other hand, companies do not have the same sort of capacities to take risks as society, which can wait for results and impacts longer. Because of the nature of basic research there is always the so-called freerider risk (if it is a risk, after all); there are always those who want to reap the benefits of research without really wanting to invest too much. It is often relatively inexpensive to duplicate and introduce existing knowledge if one does not have to pay for the original costs of producing the knowledge. Furthermore, companies' research interests may be confined to work from which they know they can gain immediate benefits. This may have adverse effects for society as a whole: R&D in the business sector may lack long-term commitment, it may become increasingly one-sided, and companies may be inclined to conceal any new information and research results. In the longer term, this may undermine research work as a whole and adversely affect the ability to adopt and apply new knowledge (e.g. Lemola 1990; Pavitt 1991; David 1997; Reinboth 2000).

In an assessment of the concrete impacts of scientific research, it is important to bear in mind the time lag between a new scientific discovery and the application that is based on that discovery and ultimately its commercialisation. Recent studies indicate that this time lag is on average 5–7 years. Earlier estimates were even longer: some reports indicated 10–15 years from applied research to innovation and over 20 years from basic research to a commercial commodity. In the natural sciences commercial innovations and profits cannot realistically be expected until 10–20 years after the initial discovery in basic research. All in all, the question of the time lag varies from case to case. In some fields of research where progress is fast, such as in the life sciences and information technology, the time lag may by now be considerably shorter. In general, the innovation process has become faster than it used to be (e.g. Mansfield 1998) – this conclusion is supported among other things by the increasing volume and rising quality standards of scientific research and by the fact that application expertise has increased, as has research collaboration in its various forms.

Innovation processes not only take a long time to complete, but they are also so complex that it is extremely difficult unequivocally to demonstrate the direct role and impact of scientific work on the emergence of innovations. What is more, the results and benefits of research may differ from what was originally intended: they may have a much broader impact in society than simply as isolated innovations. In many cases, it is also impossible to single out any one result, publication, research or project that lies behind this or that particular innovation.

For instance, a research result related to resolving a particular problem in the field of information technology may first yield a technical impact (new technical solutions are adopted on a wider scale), then an economic impact (production costs of a product or process are reduced, an innovation is commercialised and its position in the market is strengthened) and an organisational impact (production and other operations are reorganised). In the end, the impacts will begin to spread more widely throughout society, possibly leading to increased (or in some cases to reduced) welfare and social equality, for instance, and to improved life-chances for the individual or community (e.g. the introduction of lower-priced new information technology). The practical needs experienced in society towards the innovation may now begin to grow, (increased competition in the marketplace, consumer demands), and new technical and economic solutions are required to push development ahead again. At this stage, the search for new solutions to emerging problems may start up again within scientific research.

Typical examples of this process are provided by mobile phones and telephone systems. It is difficult to single out the specific role of basic research in the historical development of these technologies. If we look back far enough in history, we will find that most of today's electronic and optical devices are founded on the results of scientific research. As for the development of the information society, we need to remember that although the current equipment infrastructure is often thought of in terms of product development and commercially successful innovations and the efforts of high technology companies, the foundation has nonetheless been laid by basic scientific research and applied research.

The diversity of the impacts of scientific research is well illustrated by the direct and indirect outcomes of research in medicine and medical technology (see Lahdentausta

1988), in which the aim is to identify the causes and to describe the mechanisms of diseases and illnesses and to produce information for resolving public-health issues. In addition, collaboration among universities, research institutes, hospitals and companies produces different kinds of

- medical drugs and chemicals
- systems (e.g. data processing systems for intensive care and patient monitoring)
- diagnostic and therapeutic methods and equipment related to
  - the prevention, detection, treatment, alleviation and curing of diseases (e.g. vaccinations, microbial drugs, mammography equipment, dialysis equipment)
  - health maintenance and rehabilitation (fitness and mobility)
  - facilitating health care work (safe and inexpensive disposable medical products)
  - medical research (neuromagnetometer).

One of the most important recent innovations in medical technology is the MRI device developed at Oulu University Hospital for neurosurgery. Several of the hospital's departments were involved in the development effort that started in 1996. The project was funded among others by the Academy of Finland, the National Technology Agency (Tekes), the Ministry of Labour and several foundations and companies, and the unit was manufactured by a Finnish company in close collaboration with the hospital. There are plenty of other examples of how innovative co-operation between university research, university hospitals, funding bodies and industry has yielded significant results. Some analysts believe that medical technology in Finland is so advanced that it may well emerge as the next area of international market success. University research units and manufacturers are continuing to work to produce the technology that is needed in hospitals, operating theatres and research institutes: this equipment may eventually bring immeasurable benefits to society in the form of economic savings and improved welfare.

In an analysis of research impacts it is important that we also take account of indirect and latent effects. In practice, the only way in which we can describe the concrete mechanisms of impact is through separate case studies that focus on specific innovations and projects. However, this kind of approach only provides a limited view of the impacts of scientific research as a whole. It is not possible to do a comprehensive analysis that takes into account all cause and effect relationships. Other factors that complicate the analysis of research impact are as follows: a) the necessary statistical data are not always available; b) the collection of a sufficiently large and representative case study material requires considerable resources and is highly time-consuming; c) the comparability of different data sets, their analysis and the general applicability of results always involves various statistical and other problems. The chapters below proceed to discuss the regional and technical and economic impacts of scientific activity by looking at certain domestic and foreign examples.

4.4.2 Regional impact of scientific work

In spite of the continuing globalisation and internationalisation of science, the research evidence available indicates that there is a close national and local association between research and its exploitation: it seems that the transfer of knowledge, technology and know-how works best when the geographical distance between the producers and end-users of research is shorter (e.g. Narin & Olivastro 1992; Porter 1998; The Hot... 1998; Local... 2000) Studies have shown that scientific papers published in international journals often have only limited regional, technical and economic impact, whereas the transfer of tacit knowledge that requires geographical proximity and personal contacts, researcher transfer and research collaboration tends to have much greater significance. In spite of the trends of internationalisation the regional impact of universities is not decreasing; in fact, that impact may even increase and assume more diverse forms. Good examples of the regional impact of universities in Finland are provided by the regions of Oulu, Jyväskylä and Lappeenranta, which have created the necessary infrastructure and framework for collaboration[11].

In 1988–1996, the University of Jyväskylä ran a development programme in applied natural sciences in which the purpose was to strengthen research and education in fields that were particularly important to research, product development and production in local business companies (e.g. information technology, biotechnology, molecular biology, environmental sciences). External funding was received from local authorities, the business sector and non-profit foundations. The programme devoted special attention to improving contacts between the university and local business: this was an area that was felt had been very much neglected before the programme. In an assessment of the programme its long-term impacts were underlined. For instance, the local authorities indicated they had supported the programme with a view to boosting local business and the region's vitality in general, not so much with a view to short-term economic benefits. In the future, it is expected the development programme will produce more experts to support local business and to create new business and new innovations, jobs and skilled personnel. So far the measures introduced have had a positive impact in terms of increasing collaboration between the university and business and industry: the programme helped to create the mental foundation and physical infrastructure for a network of collaboration. The programme has also had an impact on employment in Central Finland (it has directly created some 150 new jobs and helped to maintain existing jobs) and improved the business environment by making skilled staff more readily available and by bringing more resources into research (see Nivalainen 1999).

The university may serve as a magnet that attracts business companies or as a catalyst that creates know-how, demand and networks of collaboration within its area of influence. Indeed, universities may be regarded as significant engines of regional economic growth and development and as sources of employment, culture and wealth (e.g. Helo & Hedman 1996; Ihamuotila 2000). Eastern Finland, for instance, now offers not only an increased number of student places in universities, but also better opportunities for people to remain in the area after they have graduated. That in turn strengthens the region's local economy and its cultural life. As universities continue to strengthen their special areas of expertise, however, they must also have the flexibility to adapt and adjust their profiles according to the changing needs of the environment as well as the policy decisions of other universities: that is crucial so that they can retain their special position.

11 It should be stressed that the cases described here and in the chapter below are intended as examples only: that we have chosen to look more closely at certain universities does not mean they are considered to have had better success than other universities in the topics discussed.

The University of Oulu and its environment provides a good example of the regional impact of scientific work and research and development efforts. In its operation the university has taken into account the local research and technology needs as well as the objectives of innovation development. The University, the local authorities and local business and industry have worked closely with one another for more than 20 years to bring together regional strengths and to create centres of expertise.

Special areas of strength in the Oulu region include the information industry, medical technology and biotechnology. R&D in these fields is concentrated in the city's two science and technology parks. Both science and technology parks are part of the same concern and work, in spatial sense, very closely with each other. The University of Oulu, the Technical Research Centre VTT, Technopolis Oulu and Nokia are based in the Linnainmaa area. Founded in 1982 (the oldest technology centre in the Nordic countries) and currently comprising 160 businesses, Technopolis Oulu is the centre for high-calibre expertise in electronic communications and has emerged as perhaps the most significant development centre in the whole of Finland. The other centre in Kontinkangas is built around the University of Oulu, Oulu Central University Hospital and Medipolis. The main areas of expertise here include medicine, medical technology and biotechnology.

The University of Oulu is largely responsible for meeting the training needs of the local labour force in northern Finland. Working closely with the local authorities, business and industry, science and technology parks and centres of expertise in the Oulu region, the university is a very significant and influential player indeed in the local economy. Large numbers of new companies and new jobs have been created particularly in technological fields. High-tech industries currently employ some 9 000 people in the Oulu region. The City of Oulu and its surrounding municipalities constitute a major centre of growth. Population numbers have been rising very sharply since 1997: in relative terms growth in the Oulu region is fastest in the whole of Finland. People are moving into the Oulu region not only from northern Finland but also from the southern parts of the country. The population growth in Oulu is expected to continue.

Run jointly by Technopolis Oulu and Medipolis, the influence of the Oulu Region Centre of Expertise extends through large parts of northern Finland. The centre's regional innovation strategy consists of nine projects. The focus in these projects is on areas of special expertise that directly benefit business in Northern Finland and that have the potential to generate new business in electronics, software production, space technology and environmental technology. (see Lajunen 1996; Centre… 1999; Mainio 1999; Technopolis… 2000)

Lappeenranta University of Technology provides a good example of how academic collaboration with the business community has strengthened the university's local role. This collaboration as well as specialisation have at once strengthened the university's national and international role. Lappeenranta University of Technology specialises in high-technology metal structures, key systems in the forest industry and logistics. In addition, the university has set up research-oriented networks with the forest, engineering and energy industry. The focus of these networks is on laser technology, logistics and new methods of technology management. The Metnet network coordinated by the University's Centre for Training and Development involves more than 70 companies. This network specialises in high-technology metal structures, which has proved a highly successful specialisation strategy that has had a strong local impact. On the forest industry side, the corresponding network is known as Woodnet.

The quality of research has been raised partly through local and regional co-operation. At the same time, closer links have been created between the university, the authorities, and the business community. There has also been close interaction and exchange between basic research, applied research and commercialisation. The share of extramural funding (largely from private sources) has increased at Lappeenranta University of Technology to over 30 per cent. Having worked closely with local industry for 30 years, the University has gained a good reputation and a strong position in the local economy: for instance, over 80 per cent of all master's theses in technology and half of the theses in economics and business administration are researched in companies. Lappeenranta University of Technology is also a significant source of income and employer in its region.

Lappeenranta University of Technology has played a key role in developing interaction within its own area. Its influence in this regard has been channelled primarily through the technology centre of south-eastern Finland. Founded in 1986, technology centre Kareltek has worked to develop new high-tech solutions in a region dominated by the forest industry and marred by structural unemployment. The companies that benefit most from the University's know-how work in the fields of information technology, high-technology metal construction and energy technology. At year-end 1997 Kareltek had under its wings a total of 57 high-tech companies. The numbers have increased very rapidly. Half of the 450 people working at Kareltek have graduated from Lappeenranta University of Technology. The vast majority (94%) of wages and salaries from the centre went to the Lappeenranta area (see Virtanen 1998; Anttila 1999; Kyläheiko 1999; Vähäpassi & Moitus 1999)

4.4.3 Technical and economic impacts of research and co-operation between universities and business companies

The benefits gained from research depend on how widely its results are disseminated and how successfully they are put into use. There are unfortunately no reliable methods for measuring the productivity of publicly funded research in money terms; the same applies to the measurement of research impact in general. It is for this reason that we can use no single set of unambiguous measures or indicators to assess research impact. Indeed, while we study the impact of R&D, it is important to remember that scientific research and knowledge is inherently cumulative: for instance, even if a certain study produces no concrete applicable results, it may pave the way for further studies and development work that may then achieve something that is of technical and/or economic significance.

Research collaboration between universities and business companies is crucially important to economic competitiveness: collaboration encourages and increases research in industry and speeds up the transfer of the results of academic research and their exploitation in industry. On the other hand, for certain fields of research contacts with industry may be absolutely essential, for others they may be entirely irrelevant. If we consider the significance of co-operation between universities and business from the viewpoint of research impact, we need to emphasise that certain automatic, potential impacts are already built into the motives and objectives of collaboration in the first place. Table 4.13 gives a general view of the motives and impacts of collaboration.

A key condition for successful co-operation between universities and industry is to have a mutual understanding of each other's values and operating cultures (e.g. Rosenberg & Nelson 1994; Lee 1996; Senker & Senker 1997). Industry is most typically concerned with resolving current problems, university researchers by contrast may often have other reasons for committing themselves to co-operation: they want to secure additional funding for their research, to get new equipment or other additional resources. In any discussion of the problems of research collaboration the attention frequently turns to the often deep differences in the primary objectives of universities and business and industry, their different approaches to knowledge production and their different incentive systems. The key question is how to strike a balance in the relationships between universities and business companies. Closer collaboration could benefit both if there were a proper division of labour that allowed university researchers to concentrate on long-term work rather than having to turn their attention to practical product or process development problems.

Mansfield's (1991, 1998) studies on the United States have shown that some ten per cent of all industrial products and processes could not have been developed without a significant time lag if results from academic research had not been available. The study on Germany by Beise and Stahl (1999) has shown rather parallel findings. Quite a considerable number of companies consider public, basic research as crucial to the innovation process. According to a major questionnaire survey among the biggest companies in Europe (Arundel et al. 1995), for instance, 56 per cent of the respondents regarded the specialised knowledge gained through basic research as extremely

■ Table 4.13. Motives and impacts for research collaboration between universities and business companies*.

Universities' motives:
– increased resources allocated to research and education; – improved research infrastructure (including research equipment); – support in the identification of significant research problems, access to practical research problems, and materials and practical knowledge about research topic; – opportunity for researchers and students to gain experience of research and co-operation; – support for regional economic development; – improved job opportunities for researchers and students.
Business companies' motives:
– position in the vanguard of scientific research; – direct or indirect benefits from universities' research infrastructure; – solutions to own practical research and product development problems; – access to special expertise and knowledge that is not available within the company and other knowledge and know-how spill-over effects; – modernisation of company technology; – faster introduction and commercialisation of new technologies; – opportunity to recruit researchers and students; – opportunity to expand formal and informal contacts outside laboratory; – increase in volume and standard of precompetitive research; – maintenance and development of research competencies in company (including education); – sharing risks and costs related to research; – improved corporate image.

* (e.g. Bonaccorsi & Piccaluga 1995; Report… 1995; Meyer-Krahmer & Schmock 1998)

important; 35 per cent considered it was important for the developments in instrumentation; 19 per cent indicated it was important for the development of prototypes.

The Nordic countries, and Sweden and Finland in particular, have relatively long traditions of close collaboration between research organisations in the private and public sectors. Innovation surveys conducted in the EU countries have shown that around 45 per cent of Swedish companies and 38 per cent of Finnish companies have contractual co-operation with universities or government research institutes. In other countries, the proportion of companies working closely with public sector research organisations varied from nine to 19 per cent (see OECD… 1999). According to an innovation survey by Statistics Finland covering the period from 1994 to 1996, almost 30 per cent of Finnish industrial companies regarded universities and over 19 per cent research institutes as important sources of information for innovation purposes (Leppälahti 1998). The report also lent support to the view according to which active and concrete co-operation increases the partner's significance in innovation. On the basis of these results we may conclude that in Finland public research organisations are important partners to quite a large number of companies and that there has been close and quite extensive collaboration at least since the early 1990s.

Companies are often of the view that the coded information presented in scientific publications is of limited practical significance to their own R&D work. If publications are the only avenue employed, the results will not spread very far, nor will they be adopted very widely in industry. Publications provide much stronger support for technology transfer when other channels of dissemination are also used. The best strategy for an effective transfer of new knowledge and know-how from research organisations to companies consists of three components: R&D work by the companies themselves; close and often informal personal contacts; and concrete co-operation with the research organisation (e.g. Husso 1993; Faulkner et. al. 1995). Indeed, tacit knowledge has recently assumed a position of ever greater significance alongside coded information: there is ever wider recognition now of its great role in the spread of technology and know-how (see Patel & Pavitt 1995; Shohet & Prevezer 1996).

The accent on new, formally presented knowledge often tends to overshadow the practical benefits of collaboration, which in many cases are far more important. Several international surveys indicate that science's contribution to industry in the form of academic research skills outweighs the importance of concrete research data (e.g. Rosenberg 1992; Hicks 1992; Martin et. al. 1996). The increase in know-how and ability to apply new information often prove to be particularly useful in situations where companies have to tackle increasingly complex and demanding practical problems: indeed, the role of companies is often to develop inventions and innovations further and upgrade them into commercial products. In this sense, there is a clear division of labour with universities: universities are rarely expected to produce highly advanced innovations or technical solutions. Followingly, from the viewpoint of business companies, the increase in patenting and licensing activities as such are not (at least significantly) the central elements in the development areas of universities. So, as far as companies are concerned, they are chiefly interested in the new knowledge and know-how provided by universities and especially in the transfer of technology and research methods, and in potential applications of this knowledge and know-how.

Apart from making projects possible in the first place, public support for research has important implications with respect to the way in which projects are organised and implemented: for instance, the scope of the project may be increased, its goals may be upgraded, or the commercialisation of the innovation may be brought forward. Public support in the form of additional government funding and cluster projects seems to promote collaboration and interaction between different actors in the national innovation system. It has been shown that support promotes networking and increases the use of external research resources in business companies.

In a questionnaire study by Aaltonen (1998) on academic entrepreneurship, technology transfer and spin-off companies, 62 per cent of Finnish researchers in the natural sciences, engineering and technology, and medicine indicated that they had had direct contacts with industry during the past five years. The initiative was slightly more often made by the company rather than by the researcher. The development of co-operation is often based on informal or personal contacts. Technology transfer and the setting up of spin-off companies has been most common in universities with technical facilities or research units in information technology or biotechnology. As might be expected the highest frequency of industrial contacts is reported by people in technical fields (some 90 per cent according to the questionnaire). The findings of this research indicate that especially small and medium-sized enterprises (SMEs) benefit from collaboration with

In 1999, Reijo Miettinen and colleagues published a detailed examination of six Finnish innovations and their evolution. The innovation processes involved provide useful examples of the technical and economic impact of research. The cases studied in the book are the Nordic mobile phone system NMT, enzymatic pulp bleaching, the Neuromag brain mapping device, the immunodiagnostic method DELFIA, Benecol margarine as well as Dynazyme DNA polymerase. The innovations differ from one another both in terms of the time it took to work the idea, the technology policy measures involved, public funding and the collaboration related to the marketing of the innovation.

The innovation with the greatest economic and social impacts has probably been the Nordic mobile phone network NMT. The time span of the innovation process ranged from eight years (for enzyme enhanced bleaching of chemical pulp) to 30 years (for Neuromag). In the latter case the figure refers to the whole process from early development to the introduction of a commercial instrument for clinical diagnosis. In all cases the different parties involved worked closely with one another to promote the spread and marketing of the innovation.

The motives of the people and organisations who started the innovations varied from international administrative co-operation (NMT) to safeguarding the continuity of research and research funding (Neuromag, enzyme enhanced bleaching) and business considerations (DELFIA, Benecol, Dynazyme). The stage of developing the idea ranged from two years in the case of Dynazyme to 12 years in the case of Neuromag. In most innovation projects implementation was based on a co-operation network that involved complex, multidisciplinary interaction, existing domestic and international relations of friendship as well as foreign partners' distribution and other channels.

The significance of technology policy measures and public funding to the innovations has varied. NMT is in itself a form of technology policy conducted by government authorities and national teleoperators. The projects received public funding at different stages. The National Technology Agency (Tekes) funded enzyme enhanced pulp bleaching, Benecol and Dynazyme (Finnzymes Oy). The Finnish National Fund for Research and Development (Sitra) provided funding for Otsoni Oy to keep DELFIA technology in Finland. Sitra's ownership and funding was decisive in the case of Neuromag. In many innovations key forms of funding included travel grants as well as support received for organising conferences and seminars.

The innovation that is most clearly and heavily based on research is the Neuromag brain mapping device. Public funding was perhaps in the most crucial role in the case of this innovation. The Helsinki University of Technology's Low Temperature Laboratory and the company that originated in the Laboratory, Neuromag Oy, received public funding from numerous sources: the main funding bodies were the Academy of Finland, Tekes and Sitra. In 1998, the Low Temperature Laboratory was awarded the status of centre of excellence in research for the term 2000—2005.

universities. From the point of view of universities collaboration with SMEs is easy and flexible: there is direct contact with management, personal contacts are often close, SMEs show a strong commitment to development and they concentrate their efforts on a limited number of aspects. Problems of collaboration include the limited amount of economic resources available to SMEs, the focus on daily routines and limited know-how.

Since the early 1990s, production structures in Finland have been transformed very rapidly towards knowledge-intensive growth. This has been based partly on long-term R&D efforts in both industry and universities and research institutes. The development is reflected in the sharp increase in R&D investment in the private sector as well as in increased research collaboration. However, the underlying foundation for all this is provided by the intellectual capital of a highly trained personnel. Although universities doubled and polytechnics tripled their output from information technology-related training in 1993–1998, there was still a serious shortage of skilled personnel in this sector in the late 1990s. To increase the availability of intellectual capital and to strengthen the supply of skilled people, the Cabinet Committee on Economic Policy adopted an information industry training extension programme for 1998–2002. This programme brought an extra one thousand student places in universities by the year

2000, 60 new postgraduate training places and continuing training places for 5 150 students. It is noteworthy that industry provided considerable support for the training programme: 23 companies in the information industry granted a total of FIM 47 million (EUR 7.9 million) to Helsinki University of Technology, the University of Oulu and Tampere University of Technology for the purchase of new equipment. The purpose of this one-off project is to help these universities upgrade their equipment as soon as possible so that it meets current standards (Alahuhta & Varmavuo 1999). There are many ways in which industry can support scientific research without any expectations of immediate and strict benefits: for instance, companies award funding for a limited period of time to support a new professorship or grant monies for the improvement of facilities and other infrastructure.

4.4.4 Patents as an indicator of research impact

A patent is a formal indication that essentially new and useful technological information with potential industrial application has been acquired. A patented invention may be a concrete object or a part of an object, a manufacturing or measurement method, a chemical compound or a food or medical substance. The general purpose of patent systems and patent rights is to promote technical, industrial and economic development. One of the problems with using patent indicators as a measure of the total volume of innovation activity is that not all inventions are patented. On the other hand, not all inventions can be patented in the first place: examples include computer software, scientific theories, discoveries or mathematical methods. One of the key considerations in the decision on whether or not to apply for a patent is that the whole process is extremely slow, cumbersome and expensive. The costs of applying for and maintaining a domestic patent easily run up to thousands of euros, for an international patent the figure is more likely to be counted in tens of thousands of euros. The application process often takes up many years (≥3 years). (see Edelman et. al. 1998; Lampola 1998; Kivi-Koskinen 1999)

Universities account for a relatively minor share of all patent applications, which well reflects their role in the process of technological change in society (see Pavitt 1998). Product development and testing is an area largely dominated by business companies, whereas universities tend to specialise in basic information, know-how and techniques that companies can use to tackle practical technical problems. Nonetheless, questions related to the benefits and problems of patenting and protecting the results of public research are issues of current concern in several OECD countries (see Table 4.14).

In the early 1980s, the United States broke with the OECD countries with respect to the methods applied in the protection of intangible property rights. One of the purposes of the so-called Bayh-Dole Act (BDA) that was adopted in 1980 was to encourage patenting and licensing in universities and to support the establishment of technology transfer organisations. With the introduction of BDA universities were able to gain ownership of inventions created with federal funding. At the same time, however, universities were required to strengthen the protection of their proprietary rights for research findings. The law also set out guidelines for licensing procedures (see National... 1998; Kankaala & Lampola 1999). Indeed, BDA did lead to a sharp increase in the number of university patenting and licensing offices: in 1980 only 25 universities

Table 4.14. Benefits and problems of patenting*.

Patenting is generally considered to offer the following benefits:
– Protects of research results for current and later use. – Secures product development and production. – Prevents others from illegally copying and exploiting invention and from seeking patent protection related to the same invention. – Provides source of information for research and product development: since patent documents are public, they can be used among other things to gain information on new technical solutions, to get new ideas for one's own operation and to prevent unnecessary or duplicate research. – Patenting may hugely benefit the national economy as well as the individual company concerned: an investment in inventions and patents may pay itself back many times over. For example, in 1985–1990, domestic products based on the 537 patents granted in Finland in 1985 showed a turnover in excess of FIM 10 billion. Half of the patents were commercially exploited. On average, the turnover of patented products has grown faster than the overall turnover of those firms that have patented. The patents issued in 1985 led to the establishment of 44 companies. – Patents are often the only way to succeed on emerging international markets. In some branches, it is extremely difficult to run a successful operation without strong patent protection. – Patenting is a marketing strategy and a way of enhancing the company's image: it is sign of a high technical level of research and product development and innovation. – The sale of licences may be one significant source of income generation.
Problems associated with patenting and reasons for the low level of patenting may include the following:
– The patenting process is a slow, tedious and expensive process, and there are other ways to protect new inventions (e.g. hiding information or other industrial rights such as the utility model, right to a model and trademark). – The costs of maintaining a patent are relatively high. – It is difficult, time-consuming and expensive to protect patents. – Patent follow-up and research requires considerable resources. – The red tape involved in the patenting process may be considered tedious. – People do not know enough about the patent system. – Reluctance to take risks and low tolerance of risks. – The decision to start patent application process may be complicated by difficulties in establishing the value of the invention. – There are no traditions on systematic patenting, or attitudes towards patenting are inherently negative.

* (e.g. Griliches 1990; Jyrkinen 1992; Wallenius 1992a, 1992b; Kankaala & Lampola 1998; Lampola 1998; Kivi-Koskinen 1999; Patents… 1999)

had such an office, by 1990 the figure had risen to 200. The number of reports of invention and patent applications increased significantly immediately after the introduction of BDA. However, the figures conceal a structural problem, in that a large proportion of the patents granted go to relatively few universities (such as Columbia University, University of California and Stanford University). These universities have seen a marked increase in licensing revenues. However, only a relatively small number of the licences, largely those in the field of biomedicine, account for the bulk of these revenues.

In the United States attitudes have been somewhat divided towards the BDA approach to exploiting results of research conducted with public financing. According to studies by Professor David Mowery and colleagues (e.g. Mowery 1998a, 1998b; Mowery et. al. 1998), BDA is based on the assumption that the presence of obstacles to the broader and free diffusion of research results promotes the efficiency of commercialisation. In many senses it also represents a strong faith in the linear model of innovation. Measures such as BDA are based upon a narrow view of the channels through which universities are connected to industry and through which they impact the innovation process. From the point of view of BDA, scientific publications, conferences, consultation, training or services that provide scientific advice do not have very much weight with respect to the exploitation of research results and to achieve innovations. Programmes like BDA tend to channel the operation of universities in one direction – patenting and licensing – at the expense of others.

There have been no attempts to systematically analyse the impacts of BDA on the quantity and quality of new university inventions. In any case, patenting and licensing by universities has so far failed to show a large-scale profit, with the exception of some top universities. It has also been stressed that BDA was just one factor explaining the increased patenting of universities. The long tradition of co-operation between universities and industry was probably a more significant factor in this regard.

Patents granted to universities do not provide an accurate measure of the impact of university research because the numbers involved are so small and because they draw a very narrow picture of the total impact of universities on practical applications. However, the impact of universities is clearly seen through the references to scientific articles presented in patenting documents. On the basis of US case studies it has been observed that 73 per cent of the references in industrial patents consist of references to public, mainly academic research (Narin et. al. 1997). That scientific research and innovation are becoming more and more closely interwoven is clearly indicated by the result according to which US patents increasingly often refer to research articles from the public sector. Whereas in 1985 11 per cent of all patent documents referred to at least one scientific publication, the figure in 1995 was 23 per cent. The link between patents and scientific publications cited has become tighter especially in the fields of biomedicine and clinical medicine (National... 1998). This finding is supported by results on the associations between technology fields, patent sectors and scientific publications. For instance, a review of the scientific publications cited in the patent applications submitted to the EPO in 1989–1992 allows us to identify the technology fields that are most clearly dependent on the outcome of scientific research[12]: these are biotechnology, medical substances, semiconductors, organic chemistry, foodstuffs chemistry, data processing, optics, audiovisual technology, telecommunications and materials (Grupp et. al. 1995).

Case studies on the United States, the United Kingdom and Germany indicate that in the first part of the 1990s, universities accounted for 3–5 per cent of all patent applications (Rosenberg & Nelson 1994; Meyer-Krahmer & Schmock 1997; Patel 1997; see Pavitt 1998). In absolute terms, university patents have been granted most often in electrical engineering, electronics and instrumentation. Universities have accounted for the largest proportion of all patents in the fields of chemistry, pharmaceuticals and medicine. In these fields of research much of the work done at universities has

12 In other words, the patent applications in the technology fields indicated referred to scientific publications far more often than in technology fields on average.

traditionally been very close to the kind of technical research whose results lend themselves to practical applications and by the same token to patenting. However, the concentration of university patenting in these branches does not mean that these are the only fields in which university research can produce results that have immediate benefits and economic potential.

In Finland, the number of patent applications has been declining in recent years. According to a recent survey by Statistics Finland (see Husso & Virtaharju 1999), a total of 3,136 patent applications were filed in Finland in 1998 (of which 434 came from foreign applicants). This was almost 54 per cent less than in 1995, which marked a record level of applications. The decline is explained entirely by the reduced number of applications received from foreign countries: nowadays virtually all applications for a patent in Finland go to the European Patent Office EPO. The number of Finnish applications for foreign patents has been on the increase: in 1989–1996, the number of Finnish EPO patent applications increased on average by 11.9 per cent a year. The figure was second highest in the European Union (Eurostat... 1998). In 1998, a total of almost 800 patent applications were submitted from Finland to the EPO. Finnish patenting in the United States has also shown rapid growth. In 1998, Finnish applicants received some 600 patents in the United States, almost 150 more than one year previously.

In 1998, Finnish companies submitted over 1,800 domestic patent applications, marking a 12 per cent increase on the figure for 1997. During the past two years the number of patent applications filed by business companies has indeed shown relatively rapid growth. Patent applications by private individuals accounted for almost one-third (884) of all domestic applications in 1998. By international comparison, the number of patent applications filed by private individuals in Finland is relatively high, which is explained in part by the role of university researchers. In the 1990s, the number of patent applications submitted by private individuals was in the region of 700–970 a year. By far the largest proportion of domestic applications in 1998 were related to telecommunications (some 20% of all applications). However, no national or internationally comparable data are available on university patenting either for Finland or for the rest of the world.

A questionnaire survey conducted by the Academy of Finland in winter 2000 yielded some patenting data for different universities in the country. The figures below need to be interpreted with caution, though, bearing in mind that the total number of patents applied for and received by people working in universities is higher than indicated. These people may have submitted their applications privately rather than through, for instance, the university patenting office.

- In 1992–1998, researchers from Helsinki University of Technology were granted 129 patents.
- In 1995–1998, researchers from Tampere University of Technology were granted a total of 69 patents. In addition, a total of nine foreign patents were granted in 1994 (no data available on domestic patents).
- In 1993–1999, Helsinki University Licencing Ltd had some 50 patents pending. To date, the office has signed 10 licensing agreements. During the period between

October 1996 and October 1998, the University of Helsinki innovation ombudsman received some 100 invention proposals, of which 15 led to the submission of a patent application.

- In Jyväskylä the commercialisation and other application of research results is mainly coordinated through the Jyväskylä Science Park. It was estimated that in 1995–1999, the Science Park dealt with some 30 patents or patent applications by researchers from the University of Jyväskylä.
- Questionnaire data from the University of Kuopio indicate that university researchers filed an estimated 100 patent applications in the 1990s.
- At the University of Oulu the innovation ombudsman indicated there were 23 pending patent applications submitted by university staff. In recent years, the total number of patent applications by university researchers has been in the region of 15–20 a year. However, the numbers have increased very sharply during the 1990s. For instance, in 1995–1997, the annual number of patent applications averaged 10–15.
- Researchers from Åbo Akademi University indicated they had been granted nine patents in 1999. A total of 28 patent applications have been filed in recent years by university staff. However, some researchers prefer to turn over the patent to the company with whom they are collaborating against a one-off payment or a patent royalty. Some researchers had used the services of AboaTech, which was founded in 1993: the agency has handled some 20 patent applications.

Most universities have no systematic files on the number of patent applications submitted or received by their staff members. Although the data at our disposal are fairly limited, we may nonetheless refer to the results of the case studies mentioned above to help assess the number of patent applications in Finnish universities. If universities accounted for the same proportion of all domestic patent applications in 1998 (total 2,702) as was reported in the studies mentioned (3–5%), then the total number of applications submitted by university researchers in Finland would be around 80–140. On the basis of our survey, it is more than likely that at least the lower figure is reached – at least there are no reasons to believe that the level of university patenting in Finland differs to any significant extent from the countries quoted in the examples above.

It is only during the past couple of years or so that patenting and licensing issues as well as other questions of intangible rights have begin to attract wider attention. Universities are also unaccustomed to dealing with these issues, at least on the present scale. Legislation in Finland says that the employer has the right to any invention made by a person in their employ. However, the law is not applied to university researchers. Universities in Finland have a variety of different means at their disposal with which they seek to support researchers in the process of applying for a patent or in marketing their innovation. With the continuing growth of external funding and increased co-operation it has become more and more important to have an arrangement which allows for a centralised and systematic processing of agreements related to the funding of research and the exploitation of its results. Since universities provide their universities with the material preconditions for doing research, it is only natural that they have started to claim for a share of the revenues generated by inventions, patents and innovations (e.g. Lindqvist 1999). In the future, it will in any case be necessary to find new solutions to questions of intangible rights that satisfy both the researchers, universities and their partners in co-operation. The prevailing view among researchers is that they do not want to face any rigid set of rules that is universally applied to all universities with all patent applications and patents granted.

5 The state and quality of scientific research in Finland: summary and conclusions

Finnish universities came under mounting pressures of change in the 1990s, putting the spotlight on scientific research in an entirely new way. In recent years, both decision-makers and the end-users of R&D and new knowledge have begun to underline the importance of having research findings with genuine practical applicability and utility: they must also show social, economic and industrial relevance. The scientific community has made every effort to meet these expectations, but at the same time it has emphasised the quality of research, the importance of having adequate and long-term funding and the importance of international co-operation in research. The setting that has unfolded from this interplay has injected new dynamism into the science system and boosted the efforts of universities at reform and renewal. At the same time, it has created new opportunities and new challenges, but also new problems.

5.1 Resources, output and impact of scientific research

During the late 1990s, Finland has moved somewhat closer in its development lines and themes of science and technology policy to the major R&D-intensive OECD countries. This refers mostly to the timely issues such as enhancement of co-operation between the public and private sector and between universities and business enterprises, emphasis on the impact of research and the promotion of the commercialisation of research findings. However, since the mid-1990s, a significant government investment in R&D has differed markedly from the OECD mainstream. In the 1990s, Finland along with Korea, Ireland and Sweden showed the fastest growth in the *R&D intensity* (i.e. the GDP share of R&D expenditure) in the OECD group. In 1997, Finland had the R&D intensity of over 2.7 per cent (the estimate for 1999 is 3.1%), while the average for OECD countries was 2.2 per cent and for EU countries 1.8 per cent. Indeed, on this indicator, Finland now ranks among the top countries of the world: in relative terms, the only country that still probably invests more in R&D is Sweden. Although the total R&D funding has shown very healthy development in Finland in the 1990s, the picture for university and scientific research funding is not quite as good. The rate of growth in the research expenditure of universities has been slightly above the average for the OECD countries[1], the figure for the share of universities in the total R&D expenditure has been well below that average. In addition, the share of core funding[2] in the total research expenditure of universities (56% in 1997) and the share of the Government sector in the total R&D financing (31% in 1997) have been around the OECD average.

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1 At the time of writing the latest comprehensive OECD statistics available were for 1997. Since then the amount of research funding made available to universities has grown quite significantly. For instance, in 1998 the research expenditure of Finnish universities was 11 per cent higher in real terms than one year previously. If more recent international figures were available, it is likely that Finnish universities would show quite strong growth for total research expenditure compared to other OECD countries.

2 Core funding refers to direct funding for universities granted from the Government Budget, i.e. research financed from *public general university funds* (GUF). They are the funds which universities allocate to R&D from the general grant they receive from the Ministry of Education (or from the corresponding authority) in support of their overall research and teaching activities.

The increase in the R&D expenditure of universities is largely explained by the growth of extramural funding. Indeed, a major concern for universities has been the slow development of core funding in both absolute and relative terms throughout the 1990s. This has led to a significant change in their funding structure. University departments and research teams, for instance, nowadays finance their research from a variety of different sources: the management of this kind of funding portfolio is often a difficult and time-consuming job. The imbalance between core funding and external funding has created a serious dilemma: research is increasingly conducted in the form of one-off projects, and less in the form of long-term research programmes that are crucial to developing basic skills. There is also the risk of individual disciplines and universities drifting further apart in terms of the resources available to them. All in all, the environment and conditions under which universities carry out their research – and at the same time the social relevance of research and the attainment of long-term benefits – are closely dependent on the amount of core funding allocated to them, its predictability and continuity.

Funding for scientific research is increasingly awarded on a competitive basis; to an extent one could argue that there is too much competition for funding. Core funding to universities as well as financing between the faculties are frequently allocated on the basis of quantitative measures and repeated peer reviews and evaluations. These indices and instruments tie in closely with the adoption in universities of management by results, the aim of which is to raise the quality standards of research and to give closer attention to performance and productivity in the allocation of resources. There has been some success in this respect, but universities still remain quite divided in their views on how well the new management philosophy really has worked and on how fair it is. A common criticism against management by results is that in a strict application, it gives too much weight to short-term activities and to quantitative results and efficiency requirements at the expense of quality and long-term development. In the future, there is no doubt that evaluation and the use of indicators will continue to increase. Indeed, the key issue is how the results of these evaluations are interpreted and how the indicators are used. It is important that questions of evaluation are thoroughly discussed and debated and that its tools are used in a positive and encouraging way both in universities and in the science administration; it is only on the basis of such extensive debate that universities can formulate viable development strategies and gain the broad support and acceptance that they need to put them into effect.

In many cases the impacts and benefits of research are of an indirect nature. Among other things, research produces: a) new information about different phenomena, about their distinctive characteristics and basic mechanisms; b) new research tools, methods and techniques that often have broader applicability in society; c) skilled and competent people for the labour markets, especially for knowledge-intensive jobs that require special skills and expertise; d) information to support political decision-making; e) information for evaluating the social, cultural and ecological impacts of social measures and technology; f) knowledge that can be used to produce essentially new technological solutions or to generate new scientific questions; g) intellectual capital that may lead to breakthroughs in applied research and product and process development. For example, the training of new researchers, the increase in and application of knowledge and know-how and the mobility of researchers on the labour market constitute a complex process that may be regarded at once as an outcome of research, as a mechanism for distributing research results and as an impact of research. The impacts of research are mainly scientific, technical (new technological solutions, new products and processes, patents), societal (social, cultural, regional, political and organisational) and economic.

In terms of advances in science, the main outputs of research appear in the form of publications. In 1999, a total of almost 7,000 publications authored (or co-authored with foreign colleagues) by Finns appeared in international scientific series[3]. During 1991–1999, the number of publications increased on average by 6.4 per cent a year. This was the ninth highest figure in OECD countries, and well ahead of the growth rates recorded by our toughest rivals, i.e. the United Kingdom, Japan, Germany, France, the Netherlands, Sweden, Denmark, Switzerland and the United States. In 1999, Finland accounted for 0.95 per cent of all world publications. This figure has increased propitiously since 1990, when it was 0.7 per cent. Relative to population and GDP, Finland is currently one of the world's biggest publishers in the world. On these indicators, we rank among the top four countries in the world. When the number of publications is compared against the R&D expenditure of universities and research institutes, Finland ranks 12th in the OECD group.

In all disciplines, Finland's share of world publications and citations has developed quite favourably. In 1981–1999, the fastest relative increase in the share of world publications in its field has been recorded in the social sciences (from 0.19 to 0.71%). Finland's share of world publications has long been highest in medical sciences (in 1999, the figure was 1.32%). In 1995–1999, Finnish publications were cited more often than ever before: on average, Finnish publications were cited 15 per cent more often than world publications on average (i.e. *relative citation impact* 1.15). This was the ninth highest ranking in the OECD group. Indeed, Finnish research in many disciplines nowadays enjoys far greater visibility, impact and esteem than it has done earlier. It is also noteworthy that the number of internationally co-authored publications has shown relatively strong growth.

Judging by a combined analysis of several relative indicators based on a publication and citation analysis, we may conclude that, on average, Finland ranks in positions 5–10 among OECD countries. For obvious reasons, an examination based on absolute numbers gives an entirely different picture. For instance, in 1999, the number of Finnish scientific publications was 17th highest in the OECD countries. If we take the criterion of the volume of R&D investment, for instance, R&D expenditure by universities and research institutes, Finland ranks 18th in the OECD group.

On the basis of a combination of several relative indicators[4], the top three research countries in the OECD are Switzerland, Sweden and the Netherlands. The United States also ranks close to the top by virtue of its size, visibility and impact, even though there

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3 Data from ISI's NSIOD database, which indexes by country and field of research the number of publications and citations for 1981–1999.

4 Number of scientific publications and citations and trends in these numbers, number of publications relative to GDP, research expenditure and population, level and development of impact factor and relative citation impact.

are indicators on which it does not really perform that well[5]. The next group, in the light of publication and citation analysis, consists of Denmark, the United Kingdom, Belgium, Finland and Iceland as well as France, Germany and Canada. It would be pointless and indeed impossible to try and rank-order countries more accurately than this; depending on the indicator and approach applied, the rankings may vary quite considerably. Indeed, science indicators that we have used only allow us to make rather limited and general interpretations about the quantitative and qualitative development of research in different countries.

5.2 Changes in research work and its environment

Universities have taken on a much broader role in society than they used to have earlier: apart from their traditional tasks of research and teaching, universities have been working consistently to establish closer relations of interaction with business and industry and to respond to the many and varied needs of society (including the expansion of adult education and further education). There is also much closer interaction than before within universities and between units working in different disciplines. The organisational changes in university research and the co-operation (for instance, the setting up of biocentres and joint research laboratories for different fields of research) have provided a significant boost to multidisciplinary and interdisciplinary research. All this has contributed to lowering the traditional boundaries between disciplines and strengthened interaction between basic and applied research. At the same time as work is under way in certain fields of study to develop new ways of organising research and to support research, it is essential that the structures based on traditional departments are retained and that the specific strengths of these departments are fostered.

During the past decade, there has been a marked increase in the general preparedness and willingness for collaboration. The mobility of researchers, the number of informal contact networks and interaction are all at a much higher level than previously. Indeed, Finnish research is currently more international than it has been ever before. At the same time, there has been a clear movement in research away from networks of individual researchers more towards networks of research teams and multilateral co-operation. This has been promoted by an up-to-date science policy and by developing funding instruments and other forms of support for research[6]. As a result of these trends in development, the international visibility and penetration of Finnish research have improved. However, there is some difference between individual disciplines in terms of the nature of international collaboration and its objectives: for instance, the targets set for the contents and expansion of international co-operation may vary quite considerably from one discipline to the next. In many fields of research in the social sciences and humanities, there are certain functions that arise from a background of national interests. In this case, it may often be more important to find a domestic forum for publication than to get an article published in a foreign series.

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5 For example the development of number of publications and citations, number of publications relative to GDP, research expenditure or population.

6 Researchers have been encouraged to take a more active part for instance in EU research programmes and in the work of international research organisations (e.g. CERN, EMBL). New researcher exchange contracts have also been signed with a view to increasing internationalisation and co-operation.

In the late 1990s, a number of reforms were carried out in the Finnish science system that gave rise to sometimes heated debate. The centre of excellence policy and research programmes have been aimed at creating an environment that will allow Finnish research to reach the international forefront and at supporting the main areas of strength in research. A new foundation has been created for the professional research career: the preconditions for doing high-quality research have been strengthened at all stages of the research career. Graduate schools have provided a model for resolving the structural problems of postgraduate training, allowing for more systematic researcher training and improved supervision. Postgraduate training has also become more closely tied with major research projects and centres of excellence. Both universities and the Academy of Finland have sought in their research funding to pay more attention to promoting women's research careers and to questions of equality. Nowadays women researchers are equally represented on the lower rungs of the professional research hierarchy, but they still remain underrepresented in high-level research posts and in management positions in research projects.

Universities' research infrastructure has developed favourably during the 1990s. The physical research environment has improved considerably, data networks and related services have improved continuously and core facilities for research may be described as representing state of the art. On the other hand, there are many fields of research where there are potential problems with research equipment becoming rapidly outdated. Cutbacks in the maintenance and development funds made available to library services, archives and collections are another source of some concern.

In Finland, the debate on research, the role of universities and R&D co-operation often culminates in the concept of the national innovation system. Innovation system thinking emphasises that innovation depends not only on the development and introduction of technology and on scientific research, but also on the ability of the organisations concerned (universities, research institutes, companies, public administration) to agree on common objectives and to work closely with one another towards those objectives. For instance, national cluster programmes aim to break down the traditional barriers between disciplines, organisations and operating sectors within the innovation system. Further, cluster programmes seek to strengthen knowledge and know-how in fields crucial to the national economy. The new functional and institutional structures of research have for their part increased both the collaboration and interaction among researchers and among funding bodies.

Innovation studies from EU countries indicate that in the mid-1990s, the two countries with the highest frequency of contractual co-operation between the business sector and universities and government research institutes were Finland and Sweden. Domestic surveys suggest that public research organisations are important partners to business companies and that there is a quite long tradition of close collaboration. Active and concrete co-operation is considered a key precondition most particularly for innovation. Most typically companies will expect universities to come up not with near-complete innovations or patents, but with new ideas, fresh information, methodological knowledge and special expertise they can adopt and refine in practical applications. Key challenges for the development of co-operation include such questions as whether companies are sufficiently interested in basic research and long-term development efforts, and whether business and industry makes sufficient use of postdoctoral researchers and their expertise. The closer links of co-operation that there are now between universities and business and industry have encouraged more and more researchers to set up their own businesses and in general created a more favourable atmosphere towards entrepreneurship.

One of the most critical questions for the near future of scientific research has to do with striking a balance in the relationships between universities and business companies. Increased co-operation is in the interests of both parties provided that there is a proper division of labour and that university researchers are given the opportunity to concentrate on long-term basic research. Another key issue is whether the development of the national innovation system leaves enough space for the independent development of science policy and the research system and their own internal objectives, activities and means that are not (at least primarily) constructed through co-operation with industry or activities aimed at the production of innovations.

Science policy should be built up from three different vantage-points: first, it should be developed as an independent, separate policy sector; second, it should be developed closely with technology policy, searching for points of common interest and for ways of promoting dialogue; and third, science policy should be developed as an integral part of the national innovation system and its broad perspective. As a part of the innovation system, the science system has to try and get that system working more effectively and respond to society’s needs. At the same time, it is crucially important to have a strong, independent science policy that aims to create the most productive environment possible for scientific research. If that is not possible, tensions will inevitably surface that will adversely affect the development of science policy and the innovation system.

The science system and universities in Finland have had reasonably good success during the 1990s both in terms of reaching the international forefront in scientific research and in terms of reaching the objectives of science policy and the national innovation system. In the future, it is important that efforts can be continued to strengthen the broad role and impact that universities have in society and that Finland can continue to strengthen its relative position among the major scientific and industrial countries in the world. In order to succeed, we have to make sure that adequate core funding is made available to universities, that the volume of Government R&D funding is at a sufficient level, that there is a good balance in the funding structure as a whole and that the targets set for universities are in a sensible proportion to the funds available. Continuity is also extremely important: one-off adjustments to appropriation levels will not necessarily have any long-lasting positive effects. For instance, the potential benefits to society of research launched under the Government’s additional funding programme will not necessarily materialise during the course of the programme or immediately after it; benefits that will emerge can likely be accomplished in a long-term effort.

It is important to stress of course that money is not the be-all and end-all. Funding bodies and public administration and universities themselves must also work hard to promote the development of research and its institutional structures (posts and positions, infrastructure, collaboration), to improve the quality of research and to strengthen its capacity for regeneration. All this calls for consistent strategic science policy planning that is based on open debate and exchange among all the parties involved in the science system. A key question that needs to be considered is the extent to which research needs to be steered and planned and organised; how far can research be steered and controlled before it becomes excessive? The key factors in this regard are the ability and willingness of funding bodies and research scientists to take risks and to pioneer new fields of research. In addition, it is important that research funds are always available that are not tied in advance to any specific purpose and that free research is given the space and resources it needs. To make sure that research can continue to work in a positive and encouraging atmosphere, it is essential that the Government and other political decision-makers continue to underline the importance of scientific research and its relevance to well-being in society.

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APPENDIX 1.

Scientific research and bibliometric indicators

Kai Husso and Maija Miettinen

The rapid growth of science evaluation in recent years has created a need to apply various kinds indicators to describe the volume, level and impact of scientific research. A good example is provided by the use of bibliometric indicators, which has increased in both science administration and universities. Bibliometric indicators and methods have a long history especially in medical research, where they now enjoy relatively broad acceptance and approval (see Nikkari 1995; Nieminen et al. 1995).

Bibliometrics is the quantitative study of formal scientific communication in which the focus is on the research literature. Its aim is to analyse and to model the development of science and technology (see Kärki & Kortelainen 1996: 1, 7). The first steps towards developing the methods of investigating scientific publishing and communication were taken in the 1920s in the field of information and library sciences. The purpose initially was to create the tools that were needed to study the use, coverage and adequacy of scientific libraries. Bibliometric research into scientific communication began to increase considerably during the 1960s, primarily as a result of the development of statistical methods based on frequency distributions of scientific publishing. The studies by Derek J. de Solla Price (1963, 1965) on the growth of scientific activity, its measurement and citation practices were a major boost to the use of bibliometric methods. In 1963, Eugene Garfield found the *Science Citation Index*, which initially included data on publications and citations in the most important scientific journals in the natural sciences and engineering. That database provided extensive materials for analysis and it became one of the most important sources for bibliometric studies. Today, among the most popular sources are the databases maintained by the Philadelphia-based Institute for Scientific Information (ISI): the *Science Citation Index* (SCI), the *Social Sciences Citation Index* (SSCI) and the *Arts & Humanities Citation Index* (AHCI).

Bibliometric indicators are measures of scientific publishing presented in numerical form. They are based on different components of bibliometrics, which include publication, citation and reference analyses. *Publication analysis* is primarily concerned with the numbers of articles appearing in scientific journals as well as with the co-operation between individual researchers, departments or disciplines. *Citation analysis* is usually concerned with the number of citations received by publications and their various characteristics. The purpose is to measure the attention received by articles or authors and the concentration of the citations by geographical region, organisation, discipline or field of research. *Reference analysis*, then, focuses on the number and characteristics of sources and bibliographic associations (see Kärki & Kortelainen 1996: 5–24).

Impact factor describes the average number of citations received by publications appearing in a scientific journal. It is counted by dividing the number of citations received by articles published in the journal during the two previous years by the total number of articles. For example, in ISI indices the impact factor for a scientific journal in 1999 is calculated by dividing the number of citations received in 1999 by articles published in 1997 and 1998 by the total number of articles. The impact factors of journals in different disciplines may vary quite considerably from one another. This is explained among other things by the different speed at which different disciplines react to new literature, to the life-span of publications and to differences in publishing and citation practices. The size of the research community and the heterogeneity of the field of study also have a major impact on how much is published, which series articles are published in, and how often articles are cited. For this reason, it is not possible to make meaningful comparisons of the state and quality of different fields of research on the basis of journals' impact factors.

Impact factor is so named because the number of citations is considered to indicate the visibility of the publication and by the same token its impact on research in the field of research concerned. However, it is important to stress that not all articles appearing in refereed international series are necessarily of a high standard and significant pieces of work. On the other hand, studies appearing in other journals may well be quality research with a considerable impact.

Bibliometric science indicators based on publication and citation analyses are best suited to studying the whole corpus of scientific literature either nationally or internationally, or to studying publications appearing in a certain discipline. They are also useful in analyses and comparisons of the performance and productivity of departments or research teams working within the same discipline or field of study. Nonetheless bibliometric analyses have only very limited applicability. For instance, merely on the basis of publication and citation analyses, we cannot compare in reliable manner the performance or impact of different universities, faculties, departments or disciplines, nor should the results of bibliometric analyses be used to rank-order research projects, research teams or researchers working in different fields of research, even less to make funding decisions concerning research projects (see Luukkonen 1995: 57–58; Kärki & Kortelainen 1996: 75–77; Suomen tieteen... 1997: 74–76). If bibliometric indicators from different disciplines are compared as such to one another for purposes of evaluating research quantity and quality, it is easy to ignore the distinctive characteristics of the disciplines concerned – and to proceed to draw conclusions that are not necessarily valid.

The internal diversity of scientific research finds expression in socio-cognitive and organisational differences between both disciplines and different fields of study. The differences are reflected, for instance, in the following aspects (see Luukkonen 1992, 1994, 1997; Stolte-Heiskanen 1992; Kaukonen 1996; Kärki & Kortelainen 1996; Abbott 1996):

- size and resources of the research community;
- objects of study and heterogeneity of fields of study covered;
- research materials and data collection;
- research tools;
- theoretical and methodological basis of research and its approaches;
- organisation and institutional structures of research;
- publication and citation practices;
- publication structure;

- national and international orientation of research and the relationship between the two;
- public attention received by research;
- target audience of research.

One of the main weaknesses of international citation indices (such as those maintained by the ISI) is that North American and other English-language journals are heavily overrepresented. For instance, in 1997, ISI citation indices listed no more than 15 scientific journals from Finland. Only one of these was a social science journal, i.e. *Ekonomiska Samfundets Tidskrift*. In other words, the argument that these indices are 'international' has to be treated with reservation: the picture they portray of scientific publishing and research visibility is in effect largely confined to the Anglo-American research community. The problem is most clearly felt in the social sciences and humanities, which are typically concerned with national issues and objects of study and which therefore do not necessarily have very much international interest value. In the social sciences, for instance, national research interests and traditions tend to predominate, and research results are often reported in domestic journals or series, in that country's own language. It should also be stressed that in some cases monographs and readers published at home may have a greater impact on the domestic development of the field of study than articles appearing in refereed international journals. The significance of domestic research is clearly reflected in the fact that especially in the social sciences, researchers cite studies published in their own country more frequently than one would expect to see on the basis of that country's share of world publications (Brittain 1984; Frame & Narin 1988; Luukkonen 1997: 197).

In contrast to the social sciences, research in the medical sciences and the natural sciences is often concerned with universal issues in which there is broad international interest. In these fields, research is largely based on multilateral co-operation. It follows that the number of co-authored articles is much higher than in other fields and that the total number of articles published is greater. Often the publications are short articles reporting the empirical findings of laboratory experiments.

Bibliometric indicators are not in themselves outcomes of evaluation; the key thing is how they are interpreted. The results of publication and citation analyses should always be considered in terms of what is a good result and what is a poor result. That cannot be inferred directly from the statistics, but where possible the figures have to be related to other material and interpreted in such a way that the nature and distinctive characteristics of the object under study are taken into consideration. If, for instance, we want to say something about the productivity of scientific activity, then in the analysis of bibliometric results we will need to take into account the resources available in the field of research concerned. However, this is often complicated by the lack of comparable data and by the length of the time span covered. In addition, it may well be years before the results of scientific activity and their impacts begin to surface. A publication may accrue citations over a very long period of time. In this regard, too, disciplines vary from one another. For instance, in medicine or cell and molecular biology publications are easily outdated within a few years, whereas in the social sciences there are many pieces of writing that are still frequently cited 20 years on.

Bibliometric indicators best serve their purpose as a back-up to peer reviews by experts. Indicators are highly inflexible and their objectivity may sometimes be highly misleading. It is therefore important to stress that the responsibility for their correct use and interpretation rests with both the people who are conducting the evaluation and those who are using the results (see Glänzel & Schoepflin 1994; Kärki & Kortelainen 1996).

Description of the bibliometric data used in the report

National Science Indicators on Diskette

The publication and citation figures used in this report to describe research output and impact are drawn from the *National Science Indicators On Diskette* (NSIOD) compiled by the ISI. The material in this database allows for publication and citation analyses at country and field of research level: this macro-level analysis was considered adequate in view of the focus of the present report. NSIOD contains publication and citation data for different countries and disciplines for 1981–1999. It indexes some 5,500 scientific journals in the natural sciences as well as engineering and technology, 1,800 social science journals and 1,200 journals in the arts and humanities. The total number of publications is around 11 million. Some 84,000 articles have a Finnish author.

On the basis of the NSIOD material we may conclude that scientific publishing is concentrated in the OECD countries. The bulk of the publications listed have one or more authors from OECD countries. The United States accounts for 38 per cent of the articles, the United Kingdom for around nine per cent. About one-third of the articles (33%) have European authors. The Nordic countries account for about four per cent, Finland for around 0.8 per cent.

Fields of research in NSIOD

There are two versions of the NSIOD database. The Standard version has 24 fields of research and the Deluxe version 105. In contrast to the Standard version, the latter also includes the humanities. The classification of publications into the NSIOD categories is based on the journal in which they are published. In the case of publications appearing in the multidisciplinary science journals – *Science*, *Nature* and *PNAS* – each paper is separately classified into a category regarded as most appropriate. The following types of publication are included in the NSIOD database: scientific articles, reviews, notes, and proceedings papers. All these are gathered up into one category, i.e. publications (or papers).

ISI also produces a weekly publication called Current Contents, which includes the list of contents of scientific journals in the following fields:

- Life Sciences;
- Agriculture, Biology & Environmental Sciences;
- Physical, Chemical and Earth Sciences;
- Clinical Medicine;
- Engineering, Computing & Technology;
- Social & Behavioural Sciences;
- Arts & Humanities.

Publications appearing in a certain journal are classified into a field of research on the basis of a classification of the journals. The classifications applied in Current Contents correspond to the Deluxe fields in the NSIOD database; the Standard classification is less detailed, combining categories from the former classification. Table 1 shows how the two versions relate to each other and describes the combined numbers of publications for different fields of research in 1981–1999.

Using the NSIOD

The NSIOD material was used to study Finland's publication profile, publishing activity and the international visibility and impact of its research. The analysis was confined to the OECD countries, which include most of the wealthiest and the leading research nations of the world. The classification of disciplines and fields of research applied in this report is effectively the same as that used by the OECD. It breaks down into the six major fields of science: natural sciences, engineering and technology, medical sciences, agricultural sciences, social sciences, and humanities.

We had some difficulty finding the best way to match the NSIOD's Standard and Deluxe classifications with the major fields of science used by the OECD. The classification was primarily modelled on NSIOD's Standard version, though in some instances we resorted to the more detailed Deluxe classification. Table 2 shows how the NSIOD classification has been adapted to the OECD classification of the major fields of science.

Notes on interpretation

In addition to the comments that were made earlier about the inherent differences between disciplines and between the fields of research, there are some key points that should be borne in mind in the interpretation of bibliometric indicators:

- Data for small countries easily give a distorted picture of the significance of the indicator, and the time series tend not to be very even. If, for instance, a certain country has published no more than a few articles in a certain field of research and the number of citations received by just one publication is high, that will yield a comparatively high impact factor for the whole field.

- There is some overlap in the publication data. NSIOD classifies a journal into one field of study. However, that same journal may be relevant in more than one discipline or field of research and therefore it may be classified in more than one of the seven different Current Contents publications. Since the NSIOD is compiled on the basis of separate Current Contents files, some journals appear in the database more often than once. Another cause of overlap is that the contributors to a co-authored article often come from several different countries. In this case, the same article will be counted as one publication in each country. Since it was not possible to conduct an analysis of co-authored articles on the basis of the NSIOD database, we have contented ourselves with the assumption that the problem of overlap is of roughly the same magnitude in all countries included in the comparison. The searches have been conducted in the same way for all countries.

NSIOD is based on a set and rigid classification of fields of research, which to some extent restricts the applicability of the database: after all, different countries and organisations may have very different ways of classifying scientific disciplines and fields of research. Nonetheless it should be stressed that, in spite of these limitations and the simplifications and inaccuracies they entail, the database does provide a reasonably solid basis for a description and analysis of the main trends in development in publication and citation numbers – as long as one bears in mind the restrictions of the data and the boundary conditions for the analysis.

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Table 1. NSIOD fields of research: Standard and Deluxe versions.

STANDARD FIELDS Papers 1981–1999	DELUXE FIELDS
Agricultural Sciences 292,586	Agricultural Chemistry
	Agriculture / Agronomy
	Food Science / Nutrition
Astrophysics 123,579	Space Science
Biology & Biochemistry 924,921	Biochemistry & Biophysics
	Biology, General
	Biotechnology & Applied Microbiology
	Endocrinology, Nutrition & Metabolism
	Experimental Biology
	Physiology
Chemistry 1,486,574	Chemical Engineering
	Chemistry & Analysis
	Chemistry
	Inorganic & Nuclear Chemistry
	Organic Chemistry / Polymer Science
	Physical Chemistry / Chemical Physics
	Spectroscopy / Instrumentation / Analytical Science
Clinical Medicine 2,498,812	Anesthesia & Intensive Care
	Cardiovascular & Hematology Research
	Cardiovascular & Respiratory Systems
	Clinical Immunology & Infectious Disease
	Clinical Psychology & Psychiatry
	Dentistry / Oral Surgery & Medicine
	Dermatology
	Endocrinology, Metabolism & Nutrition
	Environmental Medicine & Public Health
	Gastroenterology & Hepatology
	General & Internal Medicine
	Health Care Sciences & Services
	Hematology
	Medical Research, Diagnosis & Treatment
	Medical Research, General Topics
	Medical Research, Organs & Systems
	Neurology
	Oncogenesis & Cancer Research
	Oncology
	Ophthalmology
	Orthopedics & Sports Medicine
	Otolaryngology
	Pediatrics
	Pharmacology/Toxicology
	Radiology, Nuclear Medicine & Imaging
	Reproductive Medicine
	Research/Lab Medicine & Medical Technology
	Rheumatology
	Surgery
	Urology & Nephrology

STANDARD FIELDS Papers 1981–1999	DELUXE FIELDS
Computer Sciences 101,531	Computer Science & Engineering Information Technology & Communications Systems
Ecology / Environment 234,514	Environment / Ecology
Economics & Business 153,369	Economics Management
Education 48,600	Education
Engineering 717,509	Aerospace Engineering AI, Robotics & Automatic Control Civil Engineering Electrical & Electronics Engineering Engineering Management/General Engineering Mathematics Environmental Engineering / Energy Instrumentation / Measurement Mechanical Engineering Nuclear Engineering
Geosciences 280,118	Earth Sciences Geological, Petroleum & Mining Engineering
Immunology 179,021	Immunology
Law 35,230	Law
Materials Science 352,813	Materials Science & Engineering Metallurgy
Mathematics 184,051	Mathematics
Microbiology 258,141	Microbiology
Molecular Biology & Genetics 285,611	Cell & Developmental Biology Molecular Biology & Genetics
Multidisciplinary* 188,666	Multidisciplinary
Neurosciences 394,371	Neurosciences & Behavior
Pharmacology 278,876	Pharmacology & Toxicology
Physics 1,232,158	Applied Physics / Condensed Matter / Materials Science Optics & Acoustics Physics
Plant & Animal Sciences 758,268	Animal & Plant Sciences Animal Sciences Aquatic Sciences Entomology / Pest Control Plant Sciences Veterinary Medicine / Animal Health
Psychology / Psychiatry 315,949	Psychiatry Psychology

STANDARD FIELDS Papers 1981–1999	**DELUXE FIELDS**
Social Sciences, General 384,840	Communication
	Environmental Studies, Geography & Development
	Library & Information Science
	Political Science & Public Administration
	Public Health & Health Care Science
	Rehabilitation
	Social Work & Social Policy
	Sociology & Anthropology
Arts & Humanities categories (only in Deluxe version) 332,906	Archaeology
	Art & Architecture
	Classical Studies
	General
	History
	Language & Linguistics
	Literature
	Performing Arts
	Philosophy
	Religion & Theology

* The multidisciplinary category does not include articles from *Science, Nature* and *PNAS*; these are classified into the category of the field of research concerned.

■ Table 2. Correspondence between OECD classification of major fields of science and NSIOD classification.

OECD classification / NSIOD classification	
Natural Sciences	Astrophysics
	Biology & Biochemistry
	Chemistry
	Computer Sciences
	Ecology / Environment
	Geosciences
	Mathematics
	Microbiology
	Molecular Biology
	Plant & Animal Sciences
	Physics
Engineering and Technology	Engineering
	Materials science
Madical Sciences	Clinical Medicine
	Immunology
	Neuroscience
	Pharmacology
	Psychiatry (Deluxe)
Agricultural Sciences	Agricultural Scieces
Social Sciences	Economics & Business
	Education
	Law
	Psychology (Deluxe)
	Social Sciences, general
Humanities	Arts & Humanities (Deluxe)