SCIENCE TECHNOLOGY INDUSTRY

MOBILISING HUMAN RESOURCES FOR INNOVATION

OECD

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996) and Korea (12th December 1996). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

FOREWORD

The move towards the knowledge-based economy has placed human capital in science and technology at the forefront of the policy debate across OECD countries, not just in the area of education and labour markets but also in science, technology and innovation policy. Technological change is driving demand for skilled labour and spurring an upgrading of skills across economies. This increase in demand is not being met equally in OECD countries; reports of shortages for certain types of S&T personnel including IT workers, suggest inadequacies in supply systems or barriers to the effective matching of supply and demand. Despite the increase in higher education graduates across the OECD, the share of university graduates in science and technology compared to other fields remains quite low in many countries – and has even tended to fall in some cases. This waning interest in science and technology among youth, combined with low participation of women in S&T education and employment, pose further challenges to the ability of OECD governments to bridge the skills gap.

There is also global dimension to the demand for high skilled personnel and access to international sources of S&T personnel is becoming more important for meeting specific skill requirements. While there is little evidence of a significant brain drain from other OECD countries to the United States, the openness of higher education and research systems as well as an environment conducive to research and innovation appear important in attracting top foreign talent. In the longer-term, meeting demand for high skilled workers will require sustained investments in S&T education, not just in compulsory education but also on-job training and life-long learning. Improving the adaptability of the public research sector to changes in research and employment is also important. In all these areas, governments must increasingly partner with industry, social partners and civil society if they are to provide workers with the right S&T skills for the knowledge-based economy. This report is based on recent work by the Working Group on Innovation and Technology Policy (TIP) of the OECD Committee for Scientific and Technological Policy (CSTP).

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WHAT IS THE ROLE OF S&T WORKERS IN THE NEW ECONOMY?

Human capital, especially in science and technology, is of growing importance for innovation and technology-led economic growth. In the new economy where knowledge is the source of wealth creation, human capital becomes as important as financial capital.

Human resources in science and technology are important for several reasons. First, investment in human capital is key to innovation and growth. As both the producers and users of knowledge and technology, men and women in science and technology are at the core of the technology-led economic expansion that is creating jobs and raising living standards in OECD countries. Educated S&T workers are among the key services that the public sector provides to the private sector. The public benefits of spillovers generated by human capital are a main reason for governments to invest in public education and research training. As basic research becomes more important for technology and innovation, continued investment in S&T personnel is critical for exploiting the benefits of public research. The long-term sustainability of science and the innovation process will depend on an adequate and well-trained supply of new researchers and teachers, especially as many older researchers and professors are about to leave the workforce.

Second, firm-level evidence indicates that the share of S&T workers in firms, irrespective of firm size and sector, has an impact on the introduction of new products and processes. S&T personnel help firms appropriate and apply the knowledge from basic research in industrial applications and solve complex technological problems but also raise the overall learning capacity of firms. S&T personnel thus constitute a stock of intangible capital to the firm as much of the returns to investment in innovation are only partially secured by the generation of new products, patents or other intellectual property rights.

Third, the movement of science and technology personnel between sectors, large and small firms, and across national borders is an important conduit for technology transfer. The skills developed by graduates in S&T provide substantial economic benefits to society as graduates move on carrying with them both codified and tacit knowledge. This knowledge is especially important in newly emerging and fast-moving areas of science and technology. In addition, co-operation in research and technology largely takes place through people; scientists and researchers have long participated in national and international networks of experts. Barriers to mobility and co-operation could thus significantly weaken innovative capacity in OECD countries.

Fourth, mismatches in supply and demand for S&T personnel can have repercussions on the broader economy; shortages for information technology (IT) workers, for example, could result in wage pressure. Labour market imbalances for S&T personnel may thus contribute to unemployment and an international "brain drain".

Finally, human resources in science and technology are important because they constitute a source of entrepreneurs. Increasingly, academics and S&T graduates start up firms or participate in the creation of spin-offs from the public research sector, thereby contributing to innovation, knowledge and technology transfer, industrial restructuring and job creation. Indeed, new technology-based firms are a growing source of jobs for the highly skilled, as illustrated by evidence on employment growth of S&T personnel in SMEs. Weak incentives for self-employment and firm creation could suppress this entrepreneurial potential, however.

Box 1. **Measuring the workforce in science and technology: a difficult task**

The difficulty in measuring the population of S&T personnel arises from divergences in definitions of who to count; definitions of occupational or industrial categories; and limitations in existing data sets. One measure of the stock of S&T personnel is use of *qualification*-based data on educational level and field of study. Science and technology personnel can also be categorised by *sector* of employment (*e.g.* manufacturing, services, high tech and low tech). The OECD international R&D survey counts the stock of *researchers* and *research staff* working in R&D activities on a full-time equivalent basis. Occupational categories are perhaps most often used to classify S&T personnel. The OECD's *Canberra Manual on the Measurement of Human Resources in Science and Technology (HRST)* defines HRST as the population that has: *i)* completed education at the third level in a S&T field of study; and/or *ii)* not formally qualified but employed in an S&T occupation where the above qualifications are normally required. However, these classifications are not always so clear-cut as a person with an S&T education may not necessarily work in an S&T occupation and vice versa. Efforts are underway at the OECD and Eurostat to improve the definitions in the Canberra Manual. Yet, while statistical tools for counting human resources in S&T are being refined, it should be kept in mind that knowledge of science and technology and "literacy" in IT are increasingly required for many existing and new jobs. Therefore, policy makers should not wait for precise counts of the S&T population but should draw on existing data to benchmark performance, identify future skill and occupational demands and adapt policy.

GROWING DEMAND FOR S&T PERSONNEL

The evidence shows continued growth in demand for S&T personnel during the 1990s, especially in services related to information and communication technologies (ICT). Employment of research personnel is also on the rise characterised by stronger demand from the business sector. Shortages of workers with IT skills can limit the ability of countries to reap the productivity and growth benefits from technology. However, simply increasing the supply of specific categories of IT workers may not be sufficient to bridge the overall S&T skills gap; greater investments in job-training and involvement from non-university education providers and industry will be required.

Demand for S&T workers is growing, with personnel classified as science and technology personnel (by occupation and education) making up an estimated 20-30% of the labour force in OECD countries. Employment growth for these workers has been higher than for all other occupational categories in manufacturing and market services, while salaries have increased too. Census data show that employment grew faster for S&T personnel than for all other occupational categories in manufacturing and market services during the 1980s. This was true even in low- and medium-low-technology sectors, suggesting that although employment in these sectors is still dominated by lower-skilled jobs, increased use of technology leads to higher demand for S&T workers (OECD, 1999a). In 1997, the share of knowledge-based industries – defined as technology-/skill-intensive producing and using manufacturing and service sectors – accounted for close to 50% of business sector employment in the United States and around half of value-added in the United States but also in the European Union and Australia (OECD, 2000e).

Demand for *research personnel*[1] (a subset of S&T personnel) has also grown continuously since the early 1980s, although the growth rate slowed in the first half of the 1990s. By 1998, Finland, Sweden, Iceland, Japan, Switzerland and France led the OECD countries in terms of number of total R&D personnel per 10 000 labour force. In Finland, the number of researchers as a share of the labour force nearly doubled over the past decade. Australia,

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[1] These are defined as professionals engaged in the conception and creation of new knowledge, products, processes and systems, and in the direct management of the projects concerned. For those countries that compile data by qualification only, data on university graduates are used as a proxy for researchers. R&D personnel data are expressed in full-time equivalent.

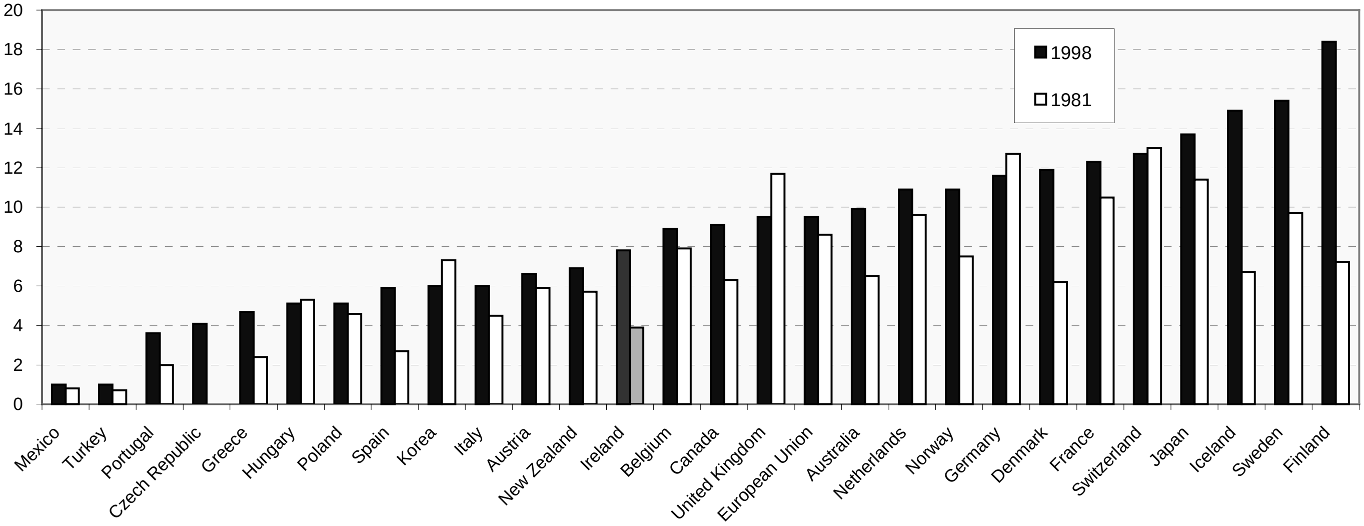
Japan, Norway and Sweden have also seen large increases, while larger European countries such as Germany, Italy and the United Kingdom made smaller gains in the 1980s and 1990s. Rapid increases in the employment of research personnel can also be noted in smaller economies such as Denmark, Portugal, Spain and Greece.

Most researchers in Japan, the United Kingdom, Germany and the United States are employed in the business sector which has continued to grow since the mid-1980s. Germany, however, experienced a drop in the mid-1990s both in the number and share of researchers working in the business and government sectors. Japanese researchers are mainly employed in the business sector, with a decreasing share working in higher education and government. The number of researchers in the US business sector – which employs around 80% of US researchers – is currently on the upswing as increases in R&D expenditures and the economic expansion increase demand. Employment in the French business and higher education sectors expanded in absolute numbers, but the overall distribution has remained broadly stable with slightly more researchers in business, followed by the higher education and government sectors. In Australia and in a few European countries including Italy and Spain, researcher employment has been greater in the public research sector since the mid-1980s. In Spain, for example, a breakdown of the data show that only 22% of researchers are employed in the business sector, and most of these work in service industries (Sanchez *et al.*, 2000).

Expansion of service sector increases demand for S&T personnel

In the 1980s and early 1990s, employment growth of S&T personnel in services outpaced the general shift of employment in OECD countries from manufacturing towards the services (OECD, 1999a). While recent data at the OECD wide level is unavailable, many of the fastest growing services sectors, such as software and telecommunication services, employ a large number of science and technology workers. The expansion of electronic commerce and related knowledge-intensive business services will increase demand for S&T personnel in services. In the United States, three broad service sectors – transportation, communications and utilities; wholesale trade; and retail trade – already account for over 80% of scientists and engineers employed in services.

Figure 1. **Total R&D personnel per thousand labour force, 1981 and 1998**



Source: OECD, *Main Science and Technology Indicators*, May 2000.

Further evidence pointing to the potential growth of S&T personnel in services emerges from OECD data on the increasing share of services in total business R&D. One-third of business R&D in Australia, Canada, Denmark and Norway is performed in services. This figure is around 20% for Italy, the Netherlands, the United States and the United Kingdom (OECD, 1999b). Because continued growth in services R&D increases demand for S&T workers, education and training curricula will have to adapt to prepare S&T graduates for the service sector where closer customer interactions require non-technical skills as well.

Implications of the increased demand for IT skills and workers

There is no doubt that the diffusion of technology is increasing demand for S&T personnel and even for skilled workers without formal S&T qualifications. Why is the labour market for information technology (IT) workers of concern to policy makers? More than any other group, IT workers are important for realising the productivity gains from investments in information and communication technologies (ICT).

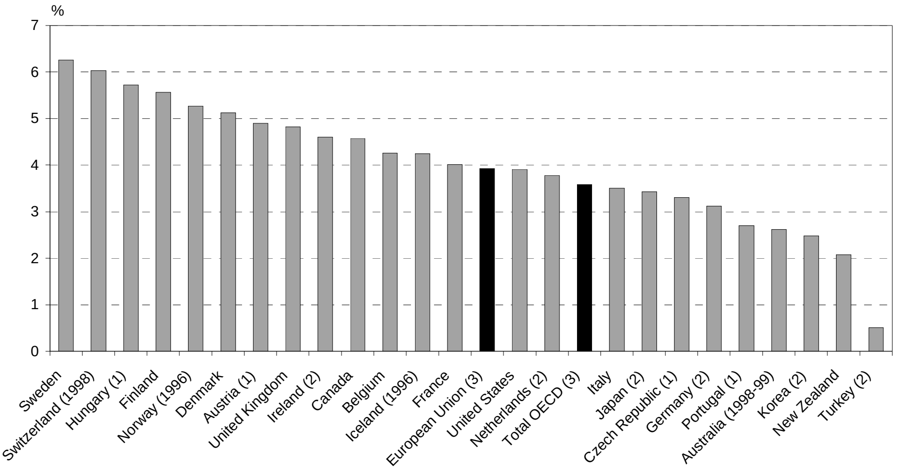
Table 1. **Employment growth in software and computer-related services**

	United States	Canada	Japan	France	Finland
1992	838 334	72 024	488 469	151 347	16 200
1993	894 256	79 921	445 662	147 881	17 000
1994	955 094	99 056	424 867	153 329	16 500
1995	1 083 977	123 312	407 396	158 544	17 400
1996	1 233 263	n.a.	n.a.	n.a.	n.a.

Source: OECD and ITAA (1998b).

Demand for IT workers across countries is not easy to measure due to the lack of a common definition with regard to the occupations or sectors that should be considered (*e.g.* IT-user sectors vs. IT-producing industries). Data on employment in the ICT sectors broadly defined indicate that an estimated 12.8 million people were working in the ICT sector in OECD countries in 1997 (excluding Greece, Luxembourg, Mexico, Poland and Spain). Around 35% of these worked in the European Union, 39% in the United States and Canada, 16% in Japan and 3.4% in the Nordic countries as a group. In terms of the importance of ICT employment relative to total business employment, the share in 1997 ranged from over 6% in Sweden to around 4% in the United States to 3% in Japan (Figure 2). The apparent low importance of ICT employment in total business employment reflects the relative size of the economies and should not be taken as an indicator of the overall impact of ICT in a country. While the data in Figure 2 are not available in time series, there is nevertheless some evidence of growing demand for certain categories of IT workers in a number of countries.

Figure 2. **Employment in the ICT sector as a share of the business sector**



1. Including all of Wholesale of machinery, equipment and supplies (ISIC 5150).

2. Excluding all of Wholesale of machinery, equipment and supplies (ISIC 5150).

3. Calculated with the available countries.

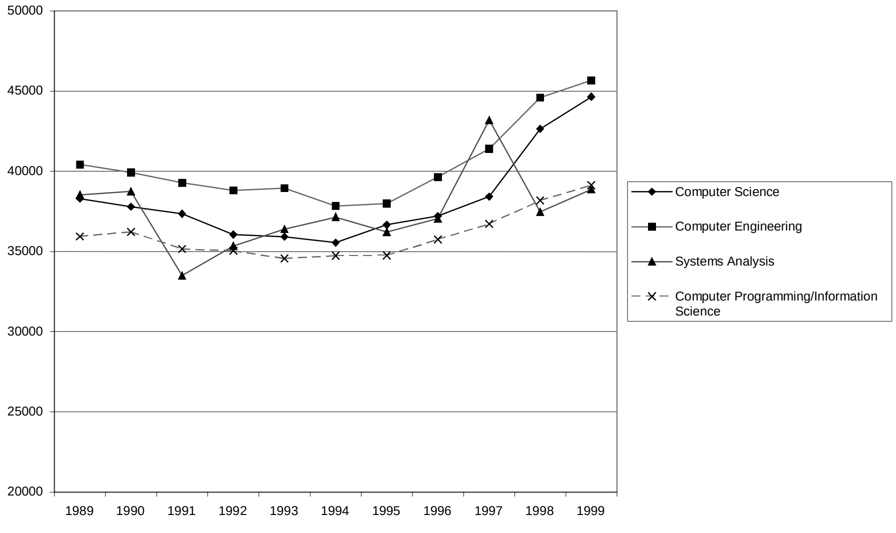
Source: OECD (2000a), mainly based on data provided by Member countries.

Employment growth for software and computer-related services professionals, for example, picked up strongly in the early to mid-1990s in the United States, Canada and to a lesser extent in Finland.

There is concern in many countries that a strong increase in demand for IT skills combined with lagging supply of qualified S&T graduates could result in shortages. A number of recent studies based on surveys from firms or other sources provide anecdotal evidence of shortages for IT workers in Germany (75 000), Canada (30 000), the United Kingdom (80 000) and France (25 000) as well as the United States (400 000) (OECD, 2000b; Forrester Research, 2000). Unemployment and wage data, while not directly confirming such anecdotal evidence, indicate sustained and strong demand for IT workers. In the United States, recent wage data for 1997-99 indicate an acceleration in the wage increases for S&T graduates in key IT occupations, such as computer science and engineering and strong increases for systems analysts and programmers (Figure 3).

Adding to the lack of conclusive evidence, the emergence of additional sources of supply including non-S&T personnel and inflows of foreign IT professionals make it difficult to assess whether shortages are likely to be severe or long term. Demand for "IT skills" in fact extends beyond demand for narrow categories of qualified personnel. According to the US National Science Foundation, in 1995 only slightly over 40% of workers in computer software engineering had a university level degree in engineering (NSF, 2000). As some IT applications become simplified and do not require workers with formal qualifications in IT *per se*; demand for IT personnel may thus not grow as rapidly as demand for IT skills. What does this mean for policy? One implication is that simply increasing the supply of "computer scientists" may not solve the IT "skills" shortage issue and will require policies for (re)training the existing workforce in IT skills.

Figure 3. **Salaries for Bachelor's degree recipients by field**
Constant 1999 USD



Source: Kuh (1999).

It also implies that universities can no longer be viewed as the exclusive source of IT skills. Vocational education institutions (*e.g. Fachhochschulen* in Germany, community colleges in the United States) as well as industry and trade associations have a greater role to play in the provision of skills;

increasingly through public/private partnerships. While the debate on the shortage of IT workers remains open, one of its principal benefits is to have raised awareness among policy makers about the need to focus on the education and training of workers for the knowledge economy.

The end of traditional modes of employment for S&T personnel?

Globalisation and enhanced competition place greater demands on flexibility and regulatory reform in product and labour markets. As a key component of R&D investment, the allocation of S&T personnel is not immune to these pressures. As firms restructure R&D departments and increase outsourcing, temporary work arrangements are on the rise. In the United States, technical staff accounted for 14% of all temporary contract staff in 1996, an increase of over 4% since 1992. This externalisation of the labour market for S&T personnel reflects the need for more flexible forms of employment in order to resolve short-term human capital needs and to respond to changing market demands. For S&T personnel, particularly recent graduates, temporary employment can also be a way to gain experience and open the way to permanent employment.

Changes in the private sector are also affecting employment in the public research sector. In some OECD countries, there has been an increase in the privatisation of research institutes and government laboratories or of state-owned firms with large research departments (*e.g.* telecommunications) and this is having an impact on the allocation of S&T labour. At the same time, large companies with industrial labs have cut R&D spending, and now outsource or purchase knowledge from new small firms and public research. As industry-public research linkages increase, public research organisations, like firms, increasingly rely on the flexibility of temporary employment to access specific expertise. In Japan, for example, a large number of young S&T personnel in the public research sector are employed in non-tenured posts or part-time positions. This trend towards more flexible employment arrangements in the public research sector is also observed in the United Kingdom and the United States where there has been an increase in graduates entering non-tenure and temporary academic employment. Labour market conditions play a role but these trends most likely reflect university requirements for flexibility and mobility, and the lowering of high costs associated with tenured employment.

ARE SUPPLY SYSTEMS ADEQUATE?

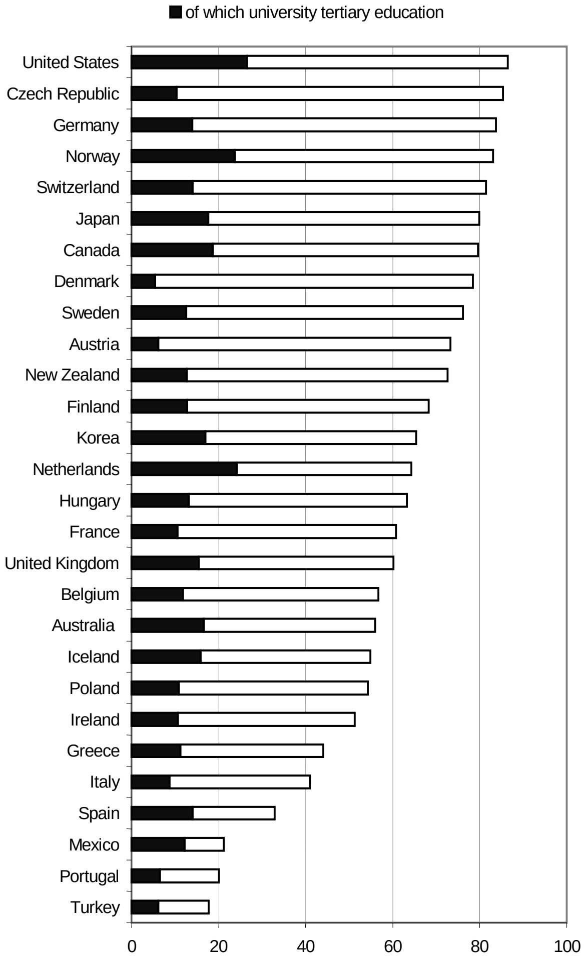
The United States, the Netherlands, Norway, Canada and Japan are the OECD countries that have the highest share of university graduates in the working-age population. The specialisation of university graduates in science and engineering is higher in Sweden, Finland, Italy, Germany and Korea. A large part of the increase in university graduates is due to greater participation of women who, despite progress, remain under-represented among science and engineering graduates, notably at the PhD level.

How do OECD countries perform in the production of a highly skilled workforce? From a purely quantitative perspective, 80% or more of the working age population (25-64 years old) in countries such as the United States, the Czech Republic, Germany, Norway, Switzerland and Japan has completed at least upper secondary education. In contrast, this figure is below half in Spain, Italy, Portugal, Mexico and Greece. With regard to higher education graduates, the share of the working age population that has a university degree is over 20% in the United States, the Netherlands, Norway, and just below that figure in Canada and Japan.

As technological and organisational changes modify the workplace, workers are called upon to draw on higher levels of intellectual capacity to deal with rapidly changing job tasks, multi-tasking and entirely new occupations. Ability in and conceptual understanding of fields such as mathematics and science is widely considered necessary for workers be able to develop problem solving skills beyond compulsory education and continue expanding intellectual capacity throughout their lives. While competency in science and technology is thus important at all levels of education, it is achievement at the post-secondary level that determines the ability of a country to produce the human capital to meet the demands of knowledge-intensive industries and extend the frontiers of human knowledge.

OECD countries differ in the specialisation of their human capital in science and technology. Sweden, Finland, Italy, Germany and Korea led the OECD area in the production of university level graduates in science and engineering and health as a *share* of total graduates in 1998 (Figure 5). The shares of university graduates in science and engineering (excluding health sciences) in France (29%) and the United Kingdom (27%) are on almost on par with those in Germany (34%). Korea and Japan, reflecting the strong specialisation in manufacturing technologies produce more university graduates in engineering than in science-related disciplines (OECD, 2000c).

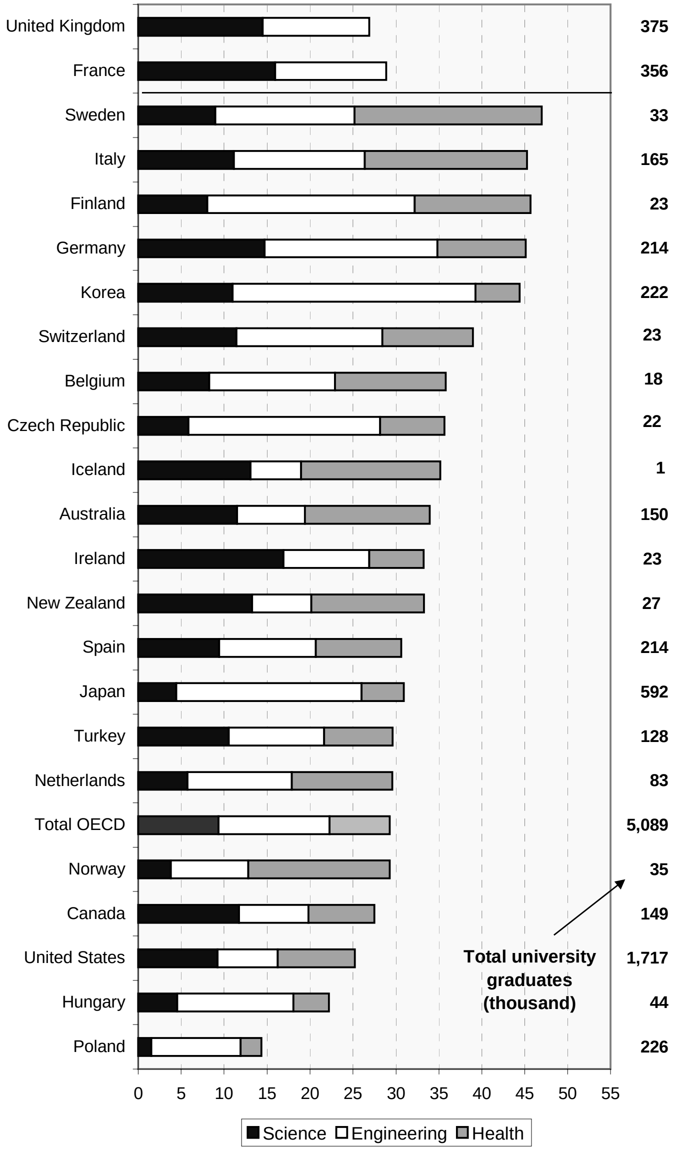
Figure 4. **Share of the 25-64 aged population with at least an upper secondary education level, 1998**[1]



1. University tertiary education includes tertiary-type A and advanced research programmes (ISCED 1997).

Source: OECD, *Education at a Glance*, 2000.

Figure 5. **University graduates in science, engineering and health, 1998**[1]
As a percentage of total university graduates



1. Science is defined as the sum of Life sciences (ISCED 42), Physical sciences (ISCED 44), Mathematics and statistics (ISCED 46) and Computing (ISCED 48). Engineering includes Engineering and engineering trades (ISCED 52), Manufacturing and processing (ISCED 54) and Architecture and building (ISCED 58). Health is ISCED 72. Data are classified according to the new ISCED 1997.
Source: OECD, Education database, 2000.

The high share of graduates in S&T in Italy reflects strength in health sciences, attracting around 20% of all university graduates. Nevertheless in Italy this strength in S&T relative to total university graduates does not offset the low share of university graduates in the working-age population.

The proportion of women in higher education has continued to increase over the past decades, even to the point of surpassing the share of men attaining tertiary higher education in Norway, Sweden and France. Still, they remain under-represented in science and technology, especially in Austria, Canada, Italy, Spain, Turkey and the United States. In general, the share of women graduates in S&T falls as the degree level rises. At the doctorate level, where women are significantly under-represented, survey data show that the share of US women PhDs in science and engineering doubled since 1988, reaching a modest 10% in 1995. In France, women account for 37% of all PhDs but they are concentrated in humanities and social sciences (National Science Foundation, 1998; Martinelli, 1999).

JOB OUTCOMES AND MOBILITY OF S&T PERSONNEL

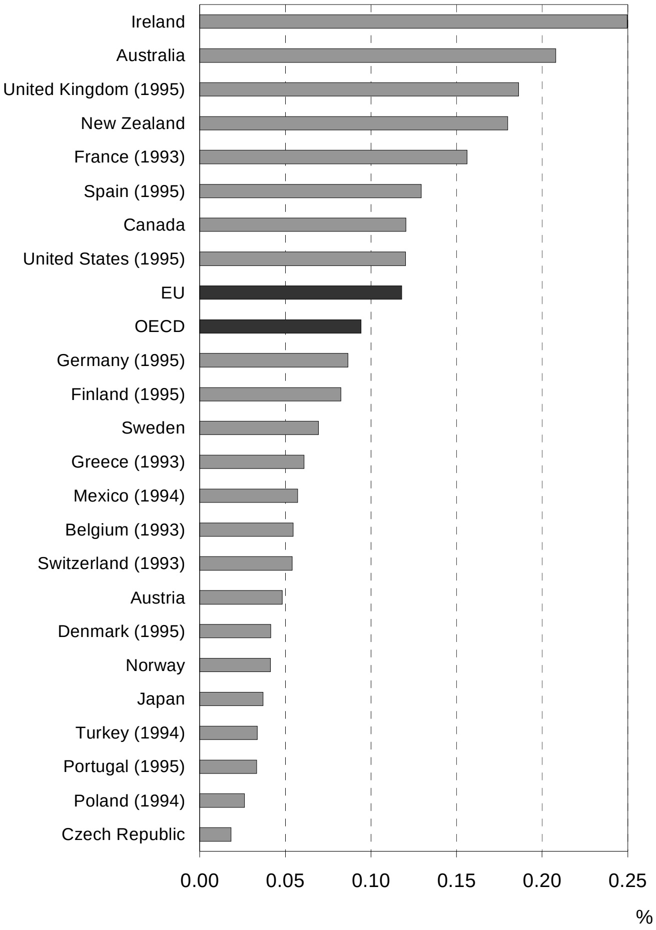
The labour market performance of recent S&T graduates is important because it affects the balance between supply and demand and signals changes in demand for different types of skills. Data on labour market flows of S&T graduates show that Ireland, Australia, the United Kingdom, New Zealand and France have the largest shares of scientists and engineers entering employment. So, while some countries have a more “intensive production” of S&T graduates (Figure 5), others are replenishing the stock in the workforce at a faster rate, due in part to education policy measures, strong demand and large cohorts of young S&T graduates entering the labour force (Figure 6).

Generally S&T graduates have higher employment and higher wages than non-S&T graduates and considerably lower unemployment rates than graduates with only secondary schooling. Graduate surveys and administrative data confirm that industry is the main destination of recent graduates in science and technology but their employment outcomes depend on their level and field of study and on demand from industry. In most OECD countries, engineers tend to find employment sooner than do science graduates.

As regards PhD graduates in S&T, universities and public research remain the main destination for doctoral graduates in the Nordic countries, Italy and Japan (for postdoctorates). In France some 60% of PhDs work in the public sector (Martinelli, 2000). In other countries (*e.g.* the United States, Canada), increasing numbers of PhDs are moving into industry and/or postdoctoral positions but some are still encountering problems entering the job market, possibly due to mismatches in technical and/or non-technical skill requirements. Postdoctoral training appears to provide a means of gaining additional training and employment-relevant experience (*e.g.* research contacts, networking, etc.), but remains a second employment choice for graduates insofar as such positions are normally temporary.

A main policy implication is that PhDs must be trained to become more adaptive to new employment situations and research demands for interdisciplinarity and IT literacy. In many cases, the excess supply of PhDs is aggravated by the fact that many graduates do not sufficiently possess the non-technical skills (*e.g.* communication, interpersonal and business skills) and the prior work experience necessary to seek employment in the business sector.

Figure 6. **Flows of graduates in science and engineering as a percentage of total employment**
1996 or latest available year



Source: OECD, *OECD Science Technology and Industry Scoreboard*, 1999; OECD calculations based on UNESCO data.

The importance of mobility

Mobility among S&T personnel is an important channel for diffusing knowledge through the economy. From a labour market perspective, mobility is also important for an efficient allocation of labour across sectors, enhancing the economic flexibility of a country. Developments in science and technology are rapid, and the degree of diversity and specialisation of knowledge is increasing.

Mobility is a necessary process which helps researchers and professionals keep up with developments in their field. Mobility also helps open new fields of knowledge as workers from different disciplines and technological areas are brought together.

Evidence from the OECD's work on national innovation systems shows that overall mobility of science and engineering professionals is high in the Nordic countries compared to the overall population. Movement of S&T personnel is generally concentrated from universities towards industry and services, with little movement in the other direction. Movement is also higher among younger researchers (Nås *et al.*, 1998).

It is estimated that in United States, scientists and engineers change jobs every four years, and more often in sectors such as information technologies. In Japan, only 20% of engineers change jobs and those that do, do so mainly at a later stage in their careers. In several countries, there remain significant regulatory barriers to mobility and disincentives to collaboration such as restrictions on dual employment of academics and researchers, portability of pensions and limits on the participation in start-up firms (OECD, 2000e). However, excessive mobility entails costs both for workers and firms. In the United States, for example, "job-hopping" among IT workers has led firms to increase wages and benefits (*e.g.* signing bonuses, stock options) in order to attract and retain workers. As workers increasingly shift jobs there are less incentives for firms to invest in their training. Universities and public research institutions can also encounter problems as top talent, drawn by higher wages but also entrepreneurial drive, moves to the private sector, reducing the pool of new professors and public researchers.

Independent of mobility, transfers of tacit knowledge could also be promoted through greater industry-science collaboration – networking and inter-firm collaboration at the very least complement external mobility. The policy implication is that while internal and external mobility should be encouraged through the removal of regulatory and non-regulatory barriers, alternatives to physical mobility, such as networking and collaboration, should also be encouraged.

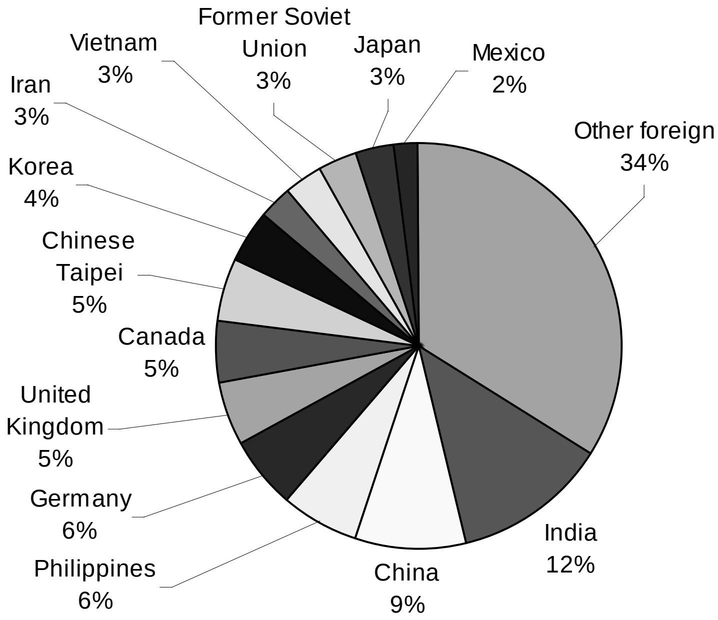
GLOBAL COMPETITON FOR TALENT

Countries whose higher education and research systems are open and have created an environment conducive to innovation and entrepreneurship attract more foreign S&T personnel. Evidence of a significant “brain drain” to the United States from other OECD countries is not conclusive. But strong funding for research, higher relative salaries, and close co-operation with industry continue to attract top graduate students and S&T personnel to the United States, at least temporarily.

The international mobility of S&T personnel is an integral feature of the globalisation of industrial R&D, but also of the internationalisation of higher education systems. OECD countries are concerned that they might lose their competitive edge in what seems like a global competition for skills in science and technology. In response, OECD countries are opening their higher education and research systems and using temporary and immigration of qualified S&T professionals to improve flexibility in adjusting to demand. There is growing evidence that the recent growth performance of the United States is in no small way linked to the role of immigration, including of highly skilled S&T personnel (OECD, 2000d). Indeed, survey evidence indicate that nearly 30% of start-ups in the Silicon Valley between 1995-98 were founded by immigrants from China and India (Saxenian, 1999). In 1995, foreign-born science and engineering personnel made up 50% of the stock of US science and engineering workforce in terms of occupation. As regards the foreign S&T population by level of qualification, in 1997 approximately 26% of PhD holders in all science and engineering fields in the United States were foreign-born; this figure was close to 47% among electrical engineering PhDs (NSF, 2000).

India, China, the Philippines, Germany, the United Kingdom and Canada are the main countries of origin for the stock of foreign-born science and engineers in the United States. The United Kingdom, Australia, and Canada are also receiving countries for S&T personnel but the United States continues to attract the largest numbers of highly skilled immigrants and students, taking in 32% of all foreign students studying in the OECD countries (OECD, 2000c).

Figure 7. **Foreign-born science and engineering degree holders in the United States, by country of origin, 1997**



Source: NSF, 2000.

The predominance of the United States in attracting foreign talent has raised concerns of a "brain drain" not just in developing countries but also in other OECD countries. While Canada is a net receiver of permanent skilled workers *vis-à-vis* most countries, it is net sending country of permanent and temporary migrants to the United States. Permanent outflows of skilled workers are small (5 000 in 1997), but there has been a recent rise in temporary skilled labour flows to the United States, ranging from between 10 000 to 16 000 in 1997 (Industry Canada, 1999). Higher marginal tax rates, lower salaries relative to its southern neighbour combined with relaxed immigration rules in the context of the North America Free Trade Agreement (NAFTA) have been evoked as factors in the recent rise in temporary migration flows of Canadian skilled workers to the United States (Table 2).

A 1999 survey of French PhD graduates found that three years after their dissertation, only 7% of PhDs resided abroad, and those that did mainly did so in order to undertake their postdoc in other European countries. Of French PhD graduates not doing a postdoc, only 2% reside abroad. Among engineers and researchers, only 1 500 resided in the United States – the same number as for nationals of Hungary and the Czech Republic. While there is thus little evidence of a significant brain drain of French scientists and engineers to the United States or elsewhere, the corollary is that few researchers and scientists come to work in France, limiting access to new ideas and opportunities for transferring knowledge. Analysis of labour force data show that the share of foreigners among engineers in French industry has stagnated at around 4% since 1990. Thus, while France experiences low levels of outflows of talent to other countries, it also does not receive large numbers of foreign skilled workers; only 3% of professionals are foreign, compared to 10% of blue-collar workers (Martinelli, 2000).

Table 2. **Salaries for IT occupations in the United States and Canada**
1999 salaries (PPP)[1]

	Canada (CAD)	United States (CAD)	Canada as a % of the United States
Entry level			
Web architect	38 157	51 243	74
Programmer/Analyst	47 898	59 078	81
Systems design engineer	39 657	49 820	79
Software developer	41 461	56 310	74
Systems analyst	54 381	68 286	80
Manager			
Web content manager software development	54 611	69 694	78
Manager	78 065	100 144	78

1. US salaries adjusted at a purchasing power parity (PPP) rate of USD 1 = CAD 1.25.
Source: Statistics Canada, Personnel Systems and Software Human Resource Council.

Although data on permanent employment do not confirm a significant or widespread loss of skilled workers from other OECD countries to the United States, there is an important qualitative dimension to international mobility. It is the loss of the top graduates and researchers in key research fields that is of concern to countries. While economic pull factors play a role, other pull factors such as strong support for research and an entrepreneurial climate of close co-operation between public research and industry may be more important. Surveys indicate that much of the international migration of scientists and engineers is in fact highly localised around knowledge-intensive clusters and in specific research areas (*e.g.* biosciences). In the United Kingdom, for example, Cambridge and Oxford Universities alone received some 15% of all foreign academics employed in the country between 1994-97 (Mahroum, 1999).

The picture that emerges is that countries whose higher education and research systems are internationalised and with an environment conducive to entrepreneurship and innovation are in general more successful in increasing the pool of foreign talent in science and technology. Countries would be short-sighted to rely too heavily on importing qualified S&T personnel in the longer term as demand conditions may change or sources of supply shift. Sending countries, especially in Asia, are themselves creating opportunities for education and employment in science and technology. Some countries, such as China and Chinese Taipei, have established programmes aimed at recruiting emigrants educated abroad.

MAIN POLICY CHALLENGES

Making S&T education and training policies more responsive to demand

As technology increases demand for S&T workers, governments and businesses must find new ways to provide workers with the skills for the knowledge economy. An increase in temporary employment, the growing importance of IT skills, enhanced university-industry co-operation and the global demand for skilled workers all mean that the conditions underlying the supply and demand for S&T workers have changed. In the new model of innovation, scientists and researchers can no longer be trained to work in laboratories isolated from societal and economic prerogatives.

Education and training policies have long focused on increasing the supply of higher education. Given the long lead times in supply and changing demand, this appears increasingly inadequate. Enhancing the *quality* of S&T education in order to improve the skills match between supply and demand and sustain the research enterprise is becoming equally, if not more, important. The debate on skill shortages also reveals that higher education can no longer be viewed as the exclusive source of S&T skills, and especially IT-related skills. Industry and trade associations have a role to play as secondary education institutions. The duration of higher education is also an issue in several countries, as long programmes can prevent early or easy exit from education to employment, increase lead times in supply and result in skill mismatches.

Interdisciplinarity in education and research is becoming more important in both the public and private sectors but the S&T curriculum and training systems are slow to adjust. This is especially the case at PhD level, where programmes are highly specialised. At the same time, interdisciplinarity leads to the emergence of new disciplines, so education policies must balance both specialisation and interdisciplinarity. The diffusion of IT and its application in S&T education and research (especially in new fields such as bio-informatics) means that S&T and non-S&T workers alike must increasingly become IT literate. Furthermore, since non-technical skills are also of growing importance, the curriculum should be broadened to build interpersonal and networking skills, and expose S&T students to business and entrepreneurial skills.

Part of the solution to problems of skill shortages can be found in alternative sources of supply; non-S&T workers, older workers and women (who are under-represented in science and engineering fields) are a potential source. This is particularly important in the IT field where men predominate in IT employment and education in most OECD countries.

The experience of some types of S&T graduates in finding employment suggests that formal S&T qualifications are no guarantee for a successful and rapid integration into the knowledge-based economy. They must be complemented with on-the-job training and lifelong learning. Lifelong learning measures should actively integrate science and technology, especially IT skills. This is becoming more important as technological change requires a continuous upgrading of skills.

Consequently, governments and firms have a stake in ensuring that workers, including the highly skilled, have incentives to invest in new skills. Governments can provide incentives for lifelong learning to firms and workers in the form of tax incentives and cost-sharing arrangements. Public partnerships between firms, government and educational institutions can help address the issue of the risks and costs of training; SMEs are particularly vulnerable to such risks as few have the resources to train workers and, under a tight labour market, may have even less incentive to do so.

One of the problems faced by firms and education systems alike in meeting skill requirements and training needs is lack of information on technological, industrial and research developments. Technology foresight exercises can complement occupational forecasts by creating a process that brings together firms, education planners and the research community to exchange information and identify potential demand for new skills.

Adapting the science system to new demands

Despite the growth in employment of S&T personnel in the business sector, government and institutions for higher education remain key employers of S&T personnel. Science and education remain among the core tasks of government even in economies where the public sector is leaning more towards the market. It is thus incumbent upon governments to ensure that there are incentive structures to attract, train and retain S&T personnel who will teach new generations of students and contribute to basic research that would not otherwise be carried out by the business sector.

In the past, public research employment was characterised by secure employment provisions and low employment turnover as well as concentrated age structures towards older workers. However, increasing returns from public research requires greater openness and renewal of the public research enterprise. Universities and public research institutes, like firms, increasingly require the flexibility of *temporary employment* to access specific expertise from outside, especially in the context of participation in research and technology partnerships with industry (*e.g.* contract research). Already, in some countries some of the basic characteristics of public sector employment, such as tenure systems and permanent employment, are giving way to more flexible arrangements. Many public science institutes have been privatised or have spun off activities for commercial purposes, and this is affecting employment relations, research prerogatives and skills.

These developments raise new challenges. The special tenure and pension arrangements in universities and public laboratories may act as disincentives to mobility. At the same time, tenure has been promoted as a way to reward academic achievement and allow scientists *independence* in research. Consequently, other incentives, including sharing in the commercial returns of public research and possibilities for academic entrepreneurship, must be promoted if researchers are to continue to pursue research and teaching in the public sector. As intermediaries between researchers and public employers, public employee unions and professional associations have an important role to play in the new employment arrangements and incentive structures that are emerging.

Leveraging human resources to enhance science and industry relationships

Innovation in firms and advances in science increasingly depend on the intensity and quality of interactions between the public research base (government laboratories and university research) and the business sector. Across OECD countries and at national and regional levels, policies have been implemented to commercialise public research. This does not happen automatically and human resources are an integral part of technology transfer and commercialisation strategies. Policies that aim to enhance industry-research interactions therefore often focus on improving mobility of S&T workers. Mobility not only benefits firms and universities, but also can benefit researchers themselves in terms of increasing human capital and building personal and research networks. There are concerns in many OECD countries that barriers to researcher mobility can weaken the pace of scientific discovery and innovation.

Regulatory barriers to mobility continue to weigh on mobility in several OECD countries, but non-regulatory barriers and weak incentive systems can also restrict mobility of public sector researchers. However, while mobility is important, excessive mobility may have longer-term repercussions on both demand and supply for S&T labour. Frequent job changes involve a loss of job-specific skills and transaction costs for workers and employers. Higher turnover could act as a disincentive for training of S&T workers. Mobility is also skewed towards younger researchers as the propensity to change jobs or sectors decreases with age.

Reforms in the science system that allow academics to co-operate with industry in the framework of public/private partnerships can enhance mobility and flows of tacit knowledge. These may include improving the portability of public sector pensions, allowing public researchers to advance their careers while working for industry or better recognising joint publication with industry. Financial incentives that reward mobility and co-operation with industry, such as IPR sharing and equity participation in spin-offs, can also improve knowledge flows and provide practical training.

Yet, universities are increasingly concerned that greater industry involvement, including mobility of researchers, may redirect their mission away from fundamental research and teaching. If academics engage in industrial projects or firms, there is less time for teaching and basic research. However, the two aims may be reconciled if academics with practical experience continue to teach and prepare students for industrial and public research.

Moreover, networking and inter-firm collaboration may complement or substitute for external mobility and may actually be preferable from the knowledge perspective. The policy implication is that, while internal and external mobility should be encouraged through the removal of regulatory and non-regulatory barriers, alternatives to physical mobility, such as networking and "virtual mobility", should also be explored.

Enhancing framework conditions for the business sector to strengthen the contribution of S&T personnel to innovation

Framework conditions in the business sector play an important role in providing incentives for students to pursue education in science and technology in the first place and, once in the labour market, in moderating the match between supply and demand. In the face of changing demand for skills or in the event of shortages, limited flexibility in wage-setting arrangements may reduce incentives for S&T workers and may lead to increased international mobility. The *OECD Jobs Study* outlined reforms in the areas of wage flexibility and overall labour mobility which can aid firms and workers to better respond to technology-induced changes in labour-market demand (OECD, 1998c). These broader labour-market reforms are often essential in meeting the more narrow demand for S&T personnel.

Framework conditions can influence the investment by firms in hiring and training skilled workers. Organisations and workers have a greater incentive to invest in training if employment relations are relatively stable and predictable. Because higher education and training, especially in S&T, has significant private benefits, firms and individuals may have to absorb a larger part of costs. This requires clear market signals for both workers and firms to invest in training. But market failures may prevent firms, especially SMEs, from hiring and training research and technical personnel. S&T policies may thus have an additional role in encouraging human capital and training investments in small firms.

Without business conditions that facilitate the creation of business start-ups, the contribution of investment in science and technology to innovation and growth will remain limited. New technology-based firms are significant employers of S&T personnel and key actors in the innovation process. At the general level, these conditions include well-functioning venture capital markets, regulatory reform to enable greater entry and exit (business start-ups and closures) and, more broadly, a business climate that rewards risk and new undertakings. If incentives for self-employment and firm creation are weak, this could lead to weak or depressed demand for S&T personnel. Finally, the degree of openness in the economy also matters, and policies relating to the permanent and temporary immigration of foreign high-skilled workers play a role in helping the business sector to adjust to demand shocks. Countries with internationalised higher education and research systems generally succeed better in increasing the pool of foreign S&T workers. Yet, countries would be short-sighted to rely too much on foreign S&T students and personnel as a source of additional supply as such reliance is no substitute for national efforts to train future generations of scientists and technology personnel. Nevertheless, science and technology policies, and in particular international technology co-operation measures, must henceforth consider immigration development and policies.

Conclusion

The move towards the knowledge-based economy is characterised by increasing demand but also by changes in the types of skills and qualifications required. The expansion of IT across economic sectors, including services, will continue to fuel the demand for S&T workers. On the supply side, there have been dramatic increases in the number of higher education graduates, especially in “catching-up” countries, but there are signs that the share of S&T graduates may be falling or stagnating in some countries. Some categories of S&T

graduates are having trouble entering the labour market as they lack the right skills even while industry reports shortages for S&T personnel in knowledge-intensive sectors. The slowness of supply systems to adjust means that partnerships between government, industry and education providers are necessary to speed labour-market entry.

The OECD's work on human resources in S&T underscores the important role that science, technology and innovation policies play in improving the match between supply and demand and enhancing the contribution of S&T personnel to scientific discovery, innovation and economic performance. Policies to promote S&T education and training must focus more on quality issues. Information technology skills should be integrated at all levels of education and lifelong learning. A number of countries such as Finland, the United States, Ireland and Denmark are taking the lead in investing in IT education to address potential shortages. Technology foresight policies can also help business and governments identify growth areas in science and technology that may have implications on skill demand and education.

Because a large share of S&T personnel are trained and work in the public sector, technology and innovation policies must ensure that the science system can attract and retain researchers. This will require adapting the regulatory framework in the public research sector to the new employment demands for flexibility, mobility and growing university-industry interactions. While reducing barriers to mobility, especially non-regulatory barriers, remains an important challenge in many countries, there are limits to and costs associated with mobility. Fostering alternatives to physical mobility for technology transfer and co-operation is also important.

Education and employment policies in research should capitalise on industry-science relationships by adjusting curricula and rules so that staff with industry experience can contribute to teaching and research. Capturing the teaching and public research benefits from industry-science interactions will also require adjustments to incentive systems. One way is to improve the rewards to academics from participating in industrial projects (*e.g.* through incentives for joint publications, sharing the rewards in joint patenting). Financing of higher education research can also be a mechanism for strengthening teaching and research missions in areas of importance to industry and society.

Governments play a key role in developing the framework conditions for the business sector but also in implementing specific policies to encourage the entrepreneurial potential of S&T personnel. In other words, policy cannot only focus on supply but must address market failures on the demand side as well. Improving the mechanisms for research commercialisation and conditions for company spin-offs and business start-ups is necessary for generating new demand for S&T personnel, especially in SMEs, and enhancing their contribution to innovation and growth.

Data issues, including problems in classifying S&T workers, continue to limit analysis. There is a potential for better exploitation and use of national data. Although most data are not gathered with the specific objective of analysing human resources in S&T, they provide a powerful political tool. In many cases, minor modifications to the existing questionnaires could enormously improve the analytical capacity of the data. Focusing on specific issues and groups might yield better results than attempting to measure stocks and flows of the entire S&T population. Maintaining flexibility in taxonomies and data collection is important. Statistical agencies and policy makers must recognise the diversity within S&T human resources. The relationship between educational qualifications and occupation is often quite loose. In addition, there are many barriers to substitution; a specialist in molecular biology is not easily replaced by a chemical engineer.

Addressing the above issues is of vital importance to innovation and the economic competitiveness of OECD economies. While OECD countries have succeeded in raising education attainment levels, especially in science and technology, the knowledge-based economy is exerting new demands for flexibility in the education and employment of human resources in S&T. In the near future, other developments such as the ageing of the workforce will pose additional challenges to policy makers.

Recent policy developments

Science and technology policies have a role in both the education and training of S&T personnel and their deployment in the private and public sectors. Together with broader labour market and education policies, S&T policies can help address policy challenges such as IT skill shortages or barriers to mobility in the public research sector. In recent years, mainstream R&D support and technology diffusion policies have begun integrating the human resource more explicitly. Box 2 provides examples of recent policy measures taken in OECD Member countries with a view to helping S&T personnel better respond to changing demand and skill requirements and improve their contribution to innovation and growth.

Box 2. **Recent policy developments in OECD countries**

Fields of policy action	OECD country examples
Reforms in the public research sector	***Germany*****:** The federal government plans to introduce more market-compatible employment and remuneration structures in higher education institutions and research establishments.
S&T education and training	***Austria:*** Austria has taken measures to introduce *Fachhochschulen* study courses as a supplement and alternative to university studies. While the national government is responsible for setting the standards for admission, the organisation of courses devolves to the provinces, communities and private bodies. This should ensure that education programmes are adapted to local needs. ***Germany:*** New framework conditions have been imposed for the German university system. A number of reforms aim at adapting the "dual system" to the ongoing structural changes in the economy. Measures to encourage the upgrading of training and facilitate access to university education, including from the *Fachhochschulen,* have also been taken. The length of study has been reduced in both the *Fachhochschulen* and universities. ***France:*** Subsidies have been granted for the hiring of S&T graduates by small and medium-sized firms in order to provide training. ***Norway:*** The Ministry of Education, Research and Church Affairs has announced policies to improve recruitment in the public sector and is creating an average of 150 posts per year over five years, notably in priority areas such as medicine, informatics and law. The Ministry also supports measures to increase the numbers of women in natural sciences and technology, and to increase their share in permanent posts, particularly at professorial level. Finally, a new programme for workplace training has also been launched. ***United States:*** Federal legislation is under consideration to amend the tax code and allow employers an income tax credit for high-technology job training. Employees already benefit from tax deductions for continuing education in their professional fields. There is legislation under review in California that would grant workers tax exemption of company-sponsored graduate education benefits.

IT skills	***Denmark:*** The Ministry of Education has launched several initiatives to foster the development of IT skills in schools and other learning centres. ***Germany:*** *The Partners' Alliance for Jobs Training and Competitiveness*, comprising representatives from government, labour and management, has agreed on a wide range of measures aimed at eliminating the current shortage of IT workers. This includes improving the infrastructure for IT in schools and universities and training of teachers in IT as well as increasing career training in IT professions to 40 000 over three years. ***Finland:*** The government has launched a public/private partnership programme whereby industry contributes to the training of new IT graduates by putting equipment and experts at the disposal of educational institutions, offering internships and encouraging their interns to graduate. The programme will involve over 20 000 students between 1998 and 2002 and is expected to increase the number of degrees by one-third between 1999 and 2006. To increase the pool of potential students, an additional programme is being launched to strengthen education in mathematics and science. Measures are also being taken to find ways to attract more female students to the fields and alleviate the shortage of qualified teachers. ***Ireland:*** The Irish government has committed IRP 95 million to addressing problems related to skill shortages. ***United States:*** The Labor Department is investing USD 8 million to create the largest electronic job and resumé database in the country. It is merging America's Job Bank – the country's largest job openings database – with America's Talent Bank – a database of worker-posted resumés, in order to improve the match between high-technology job opportunities and US workers. The Department of Labor recently awarded USD 3 million in demonstration projects to train dislocated workers for high-technology jobs. And the Departments of Education and Labor have awarded USD 6 million in grants to expand industry involvement in School-to-Work Systems. The Commerce Department's Go4IT! Web site promotes partnerships between industry and education providers to expand IT skills at regional and local levels.

	United Kingdom: The UK government recently announced a series of initiatives to foster better IT skills in the workforce. These include efforts to connect all schools, libraries, colleges and universities to the National Grid for Learning by 2002; the launch of the University for Industry in 2000, using new technology to deliver lifelong learning at home, at work and in the community, with IT skills a key target area. Under the proposed National IT Strategy, 80% tax breaks will be granted for Individual Learning Accounts when used for ICT training.
Researcher mobility and co-operation with industry, including SMEs	***France:*** The Ministry of Research's *Concerted Action Programme for Young Researchers* provides financing for three-year projects to incite young researchers and professor/researchers in universities and research foundations to explore work in new areas. Project selection is based on scientific excellence including interdisciplinarity and evaluation is conducted *ex-post*. ***Japan:*** Japan's latest Basic S&T Promotion Plan, which outlines a series of regulatory reforms to the labour market for public sector research, aims to improve mobility between the public and private research sectors. ***Netherlands:*** The Netherlands' *KIM* scheme that promotes the movement of technology personnel to SMEs has proved successful. Furthermore, under the WBSO (Act to promote R&D), small firms are allowed a tax deduction for the labour costs of R&D staff. ***Norway:*** The FORNY scheme for researcher-based spin-offs is entering its third phase. ***Sweden:*** The NUTEK competence centres at universities promote collaboration between public researchers and those in firms which may help break down non-regulatory barriers to mobility. ***United Kingdom:*** The Faraday Programme promotes a continuous flow of industrial technology and skilled people between industry, the universities and intermediate research institutes. A key element of the concept is the training and development of doctoral students who combine technical expertise with commercial awareness by undertaking industrially relevant research within intermediate institutes. In 1999, the Faraday Programme was to be expanded with a focus on entrepreneurial activities and research commercialisation.

International mobility of S&T students and personnel	***Finland:*** The government has taken steps to encourage the enrolment of foreign students in Finland, including from Asia. ***France:*** Several recent measures seek to facilitate the temporary migration of foreign scientists and researchers. ***Germany:*** The government seeks to increase foreign student inflows through grants and fellowships schemes. In addition, the government plans to issue some 20 000 immigration visas to fill an estimated 75 000 IT job vacancies. ***Japan:*** The government seeks to double the number of foreign students (50 000 in 1997) by the year 2000 through the use of scholarships (National Science Foundation, 1998). ***United States:*** The US Congress has temporarily increased the annual cap on the number of temporary visas granted to professional immigrants under the H-1B visa programme whose statutory limit is presently set at 115 000 visas per year.

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