CHAPTER 1.8

R&D and Innovation in the ICT Sector: Toward Globalization and Collaboration

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This chapter analyzes recent developments in increasingly globalized information and communication technologies (ICT) research and development (R&D) and innovation.[1]

Global structures of R&D, science performance, invention, and innovation are in transition.[2] The main dimensions of change are the absolute growth of R&D and innovation-related activities; the rise of the BRICS' economies in scientific and technological fields;[3] significant globalization of R&D; more performance of R&D in the services sector; and a growing focus on non-technological innovation, enhanced internationalization and mobility of highly skilled people, and increased internationalized patenting.

Among the main elements underpinning these developments have been the increasingly knowledge-driven nature of innovation; the quickly changing organization of research, driven by information technologies, collaboration, and the sharing of knowledge; and changes in markets, the competition environment, and technology. Firms are also embracing "open" innovation approaches and actively cooperating with external actors.

The next sections cover this trend toward more international and collaborative ICT R&D.

Globalized R&D agenda in ICT

While ICT-related research challenges and priorities are evolving, an increasingly globalized ICT R&D agenda is emerging with eight broad priorities (Figure 1).

Some of the research topics listed in Figure 1 have been in the ICT R&D agenda for some time, especially those clustered around the physical foundations of computing, computing systems, and software engineering. Optical and quantum computing, robotics, and artificial intelligence also remain important for addressing long-term challenges. In practice, R&D in a given area has led to the emergence of new topics: for example, the rapidity with which semiconductors are being miniaturized has made nanotechnology research part of core ICT R&D; mounting demand for high-speed broadband is driving research into all-optical networks and optical computing. Progress in biotechnology, nanotechnology, cognitive sciences, and interdisciplinary research fosters synergy and convergence and opens up new research areas.

ICT R&D and innovation also increasingly intend to address pressing socioeconomic challenges, which are now international in scope and reach—for example, climate change, health care, and aging societies (Figure 2).

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Figure 1: ICT R&D priorities (clusters of topics and subtopics)

Source: OECD.

Figure 2: Examples of ICT R&D as solutions to pressing global socioeconomic challenges

Source: OECD.

ICT sector R&D expenditures in the Organisation for Economic Co-operation and Development (OECD)

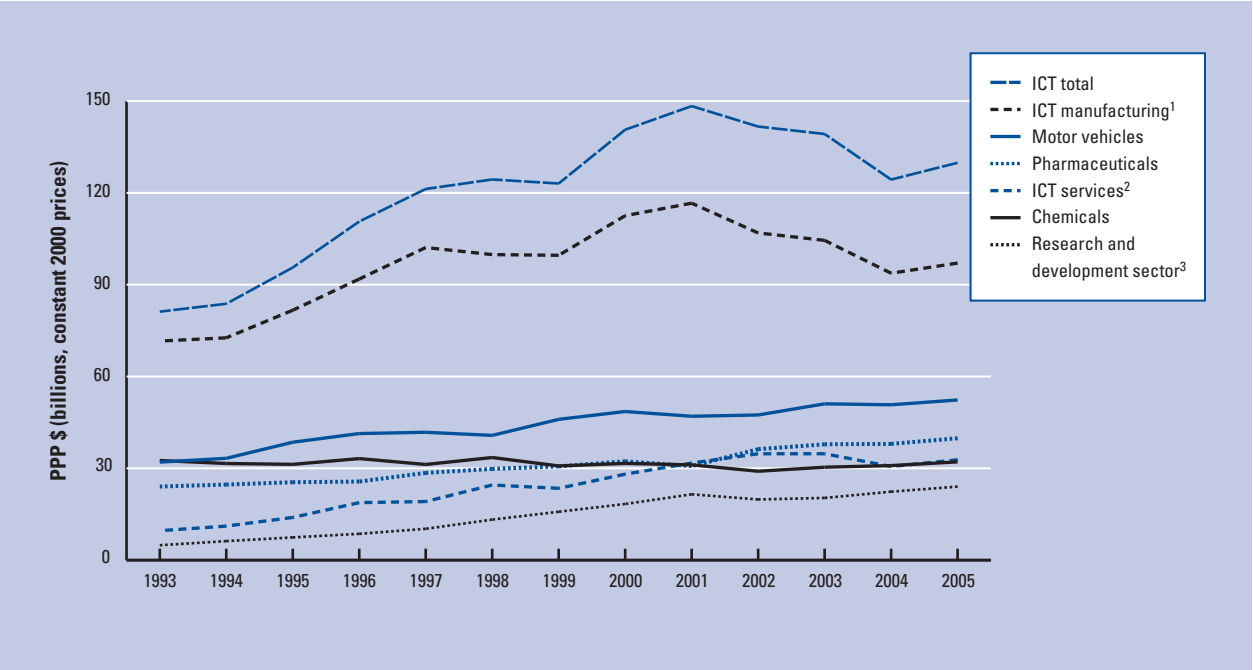
In light of the above challenging research agenda, the ICT sector undertakes large investments in R&D and is very innovative. In terms of R&D expenditures, patents, and venture capital investment, it exceeds other industries by a large margin. ICT is the most important of the five sectors that dominate business-sector R&D (Figure 3). In 2005, the OECD 21 ICT goods and services sector spent about two and a half times as much on R&D (US$130 billion) as the automotive sector and more than triple the pharmaceutical sector.[4]

In 2005, the year of the latest available official data, ICT manufacturing R&D accounted for more than a quarter of total manufacturing business R&D expenditure in most OECD countries. It accounted for more than half in Finland and Korea, Rep. (Korea) (63 percent and 57 percent, respectively), and more than 30 percent in the United States (39 percent), Australia (32 percent in 2002–03), Canada (39 percent in 2005), Japan (36 percent in 2005), and Ireland (34 percent).

The decline in R&D in the ICT goods sector since 2001 (constant terms) has been partly balanced by an increase in ICT services, which have grown very rapidly since the 1990s. These services surpassed the chemical sector in 2001 and almost reached the level of expenditure in the pharmaceutical sector. There has been a very significant growth in the share of services in computer and related activities (largely software and IT services): 21 percent in 2005, up from 9 percent in 1993.

The United States still accounts for 40 percent of all OECD R&D expenditures in ICT manufacturing and services. The European Union (EU) 15 accounts for a little under a quarter of the total, Japan for 22 percent, and Korea for 9 percent, with the larger OECD members making up the bulk of the remainder in 2005.[5]

Figure 3: Growth of the largest R&D-spending sectors in the OECD 21 area, 1993–2005



Source: OECD estimates based on ANBERD and RDS databases, June 2008.
1. Office, accounting and computing machinery (ISIC 30); Radio, TV and communication equipment (ISIC 32); Medical, precision and optical instruments (ISIC 33).
2. Telecommunications (ISIC 642) and in some cases ISIC 64; Computer and related services (ISIC 72).
3. Research and development (ISIC 73): Research and experimental development on natural sciences and engineering and on social sciences and humanities.

In ICT manufacturing, Finland, Korea, Japan, Sweden, and the United States have higher than average shares of R&D expenditure in GDP. Finland and Korea have increased their shares since 1997, and estimates for 2006 show a further pick-up for Korea. As a share of GDP, Denmark, Finland, Ireland, and Sweden have the greatest specialization in ICT services R&D (Figure 4).

Expenditure on software R&D has risen most rapidly of all parts of the ICT sector. Data on business R&D in computer and related services for 2006 show that the United States leads by a large margin (US$30.5 billion), roughly 15 times that of Israel (US$2.1 billion), Japan (US$2 billion), the United Kingdom (US$2 billion), and Germany (US$1.9 billion). The same applies to business R&D in software consultancy and supply: the United States (US$17 billion) carries out around 10 times more R&D than Germany (US$1.8 billion), followed by Korea and France (US$0.9 billion each).

Also, the global distribution of R&D is changing, and some non-OECD economies are becoming important ICT R&D spenders. Sectoral spending data are hard to produce in a way that allows direct comparison, however, for these countries at the aggregate level.

R&D spending of top ICT firms

The R&D spending of the top ICT firms has grown consistently over the last decade and held up well during the years following 2001, reaching US$151 billion in 2006 and expanding in 2007. The question is how ICT firms will react to the current economic downturn, with recession forecasted to last OECD-wide until 2010: that is, they may either significantly reduce their R&D spending or decide to maintain this spending to preserve their competitiveness in the medium to long term.

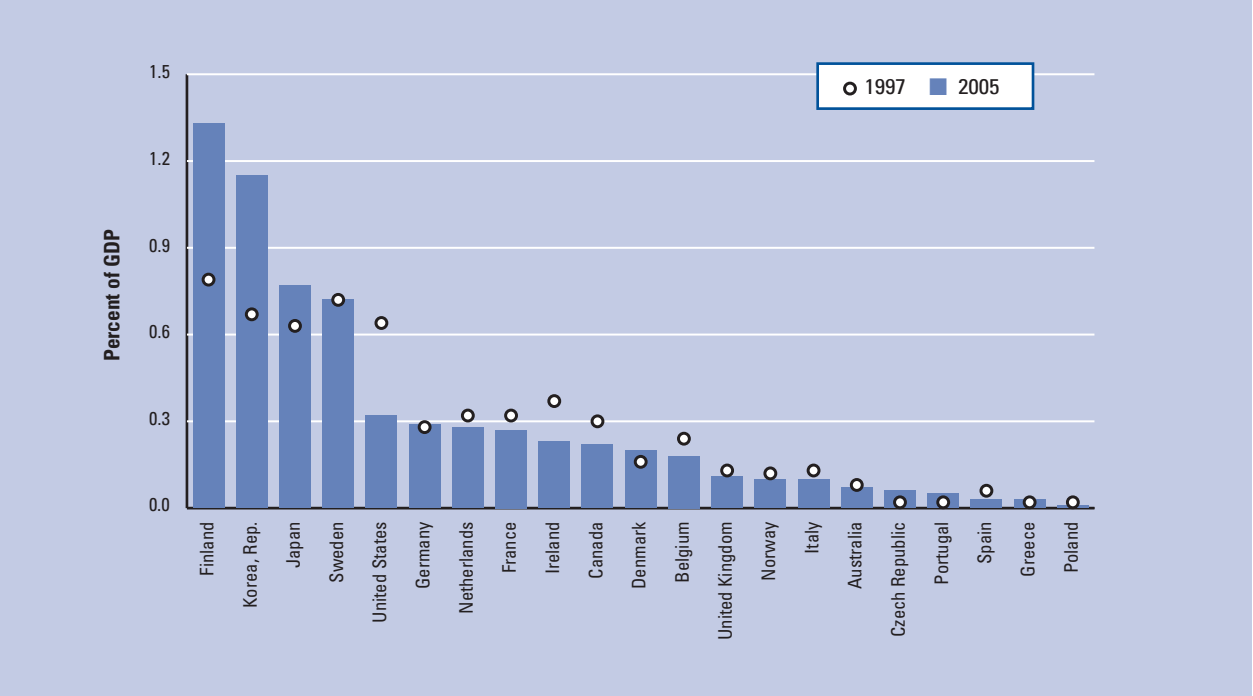
Currently, R&D expenditures of the top ICT firms are significantly higher than those of R&D-intensive firms in the chemicals, pharmaceuticals, or automotive sectors.[6] In 2006, the top 100 ICT R&D-performing firms (ranked by absolute R&D expenditures in 2006) spent an average of 6.7 percent of revenues on R&D. And, as will be explained later, these R&D expenditures are increasingly spread internationally.

The bulk of ICT R&D of the top 250 ICT firms is conducted by US (43 percent) and Japanese (26 percent) firms, followed by firms from Germany (11 percent), Korea (8 percent), and other European countries. Firms from Chinese Taipei,[7] in particular, have overtaken firms from Canada and the United Kingdom in their R&D spending. Despite rapid growth, Chinese ICT firms still have a relatively small share of the R&D expenditures of the top 250 ICT firms.

Korean firms have caught up to firms from other advanced OECD countries. Despite initial high starting levels, German and US firms have also significantly stepped up their R&D spending. Japan had a slight increase and France a slight decrease. Canada has also seen a drop, owing to spending declines by Nortel Networks and Celestica. In terms of growth in R&D spending 2000–06, firms from Chinese Taipei and China are leading, albeit from low levels (Figure 5).

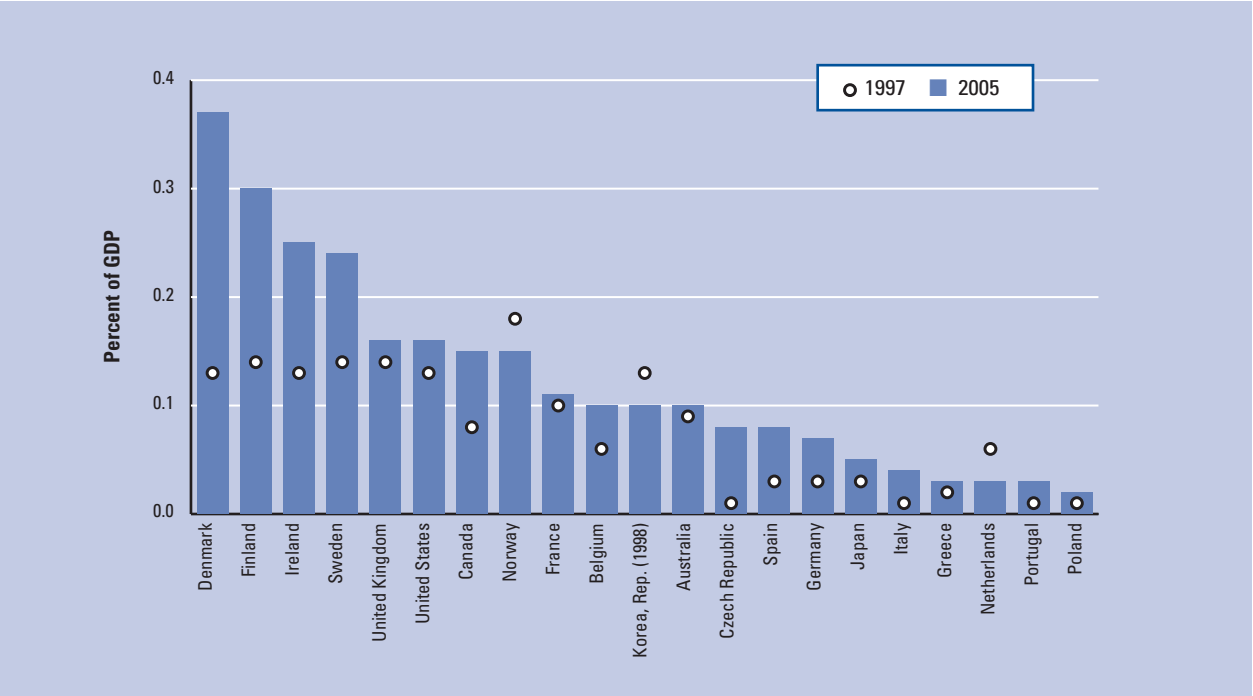
Figure 4: Business R&D expenditure for ICT goods and services, 1997 and 2005

4a: Selected ICT manufacturing industries



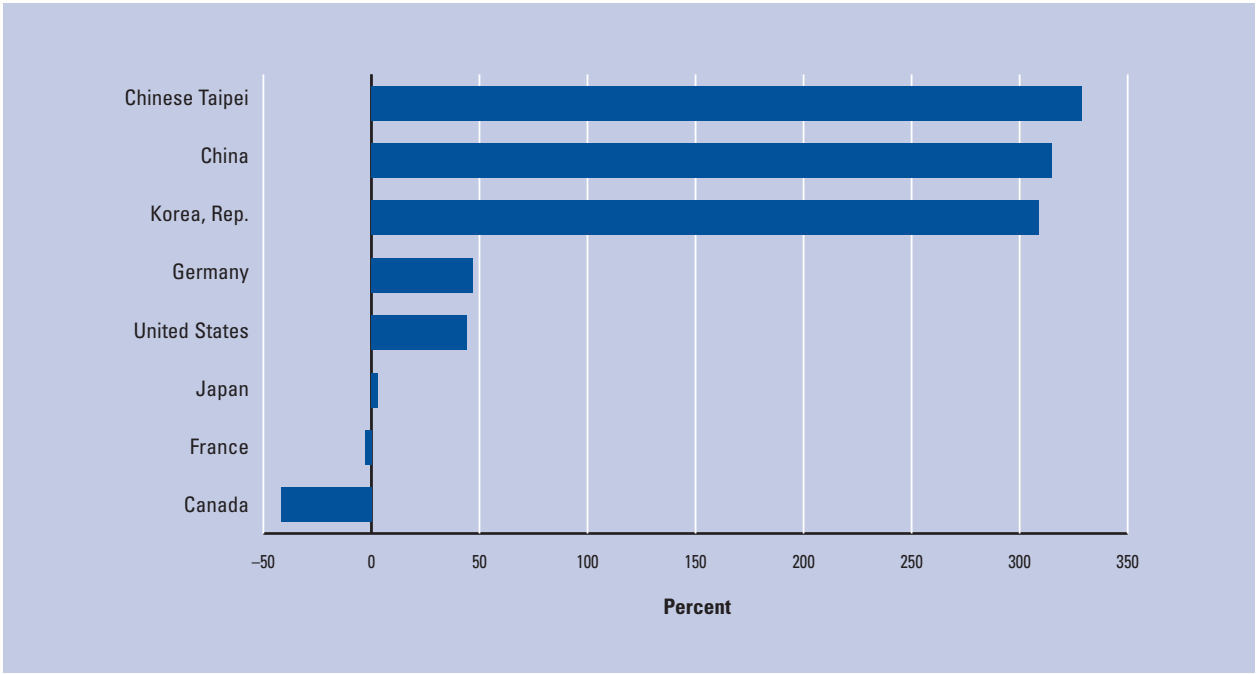
Source: OECD estimates based on ANBERD and RDS databases, June 2008. See also OECD, 2007.
Note: When data for class 642 (Telecommunications) are unavailable, division 64 (Post and telecommunications) is used. Class 642 has the major share of division 64 R&D expenditure; for example, in the United States, class 642 accounts for 97–98 percent of the R&D in division 64.

4b: Selected ICT services industries



Source: OECD estimates based on ANBERD and RDS databases, June 2008. See also OECD, 2007.
Note: Research and development (ISIC 73): Research and experimental development on natural sciences and engineering and on social sciences and humanities.

Figure 5: Growth of R&D expenditures of top ICT firms, 2000–06 (current terms, percent)



Source: OECD *Information Technology Outlook* database.

Other than China and India, ICT companies from OECD enhanced engagement countries (Brazil, Indonesia, and South Africa) and OECD accession countries (Chile, Estonia, Israel, Russia, and Slovenia) are not in the top R&D spending group.[8] In some cases, this may be due to lack of reporting (e.g., some Israeli and Russian ICT firms potentially qualify for inclusion, but no data are available). In most cases, however, R&D expenditures or revenues of these countries' ICT firms are not high enough.

For the top 100 R&D-spending ICT firms, the largest shares are in electronics (33 percent), IT equipment (19 percent), communications equipment (17 percent), and semiconductor firms (14 percent). Telecommunications firms have progressively reduced their R&D expenditures and made up only about 5 percent of the top 100 total in 2006.[9] The largest growth of R&D expenditures over the period 2000–06 was in sectors with lower initial shares: Internet, software, and semiconductor firms.

Top ICT R&D spenders by firm

Microsoft, Samsung, IBM, and Intel lead the list of ICT firms ranked by R&D expenditure (Table 1). In 2007, Samsung overtook IBM in reported R&D spending. The first three firms were also top R&D spenders across all industries in 2006, just behind Toyota Motor (US$7.7 billion), Pfizer (US$7.6 billion), and Ford Motor Corp. (US$7.2 billion) in the automotive and pharmaceutical sectors.

In terms of growth in R&D spending, the leaders are Google (114 percent, Internet firm), SanDisk (91 percent, IT equipment), Research in Motion (63 percent, communication equipment), Lenovo (54 percent, IT equipment) and Nvidia (42 percent, electronics and components) (all compound annual growth rate (CAGR), in current US dollar terms), followed by a group of Internet, service, and software firms despite their smaller number in the overall top 250 (Table 2). China and India each have one firm in the top 10 in terms of growth.

Non-OECD firms are over-represented in terms of R&D growth, in part because of their low starting level. Apart from Lenovo (China) and Infosys (India), which are in the top 10, there are a significant number of IT, electronic equipment, and semiconductor firms from Chinese Taipei (Lite-on Technology, AU Optronics, Taiwan Semiconductor, Benq/Qisda) and communication equipment firms from China (Huawei, ZTE) among the top 50.[10]

Semiconductor and hardware firms (communication and IT equipment, electronics) are the most intensive in terms of R&D expenditures per employee. Broadcom (semiconductors) leads with US$213,000 per employee, followed by Qualcomm (communications equipment), Nvidia (electronics and components), and SanDisk (IT equipment). Software firms such as Electronic Arts, Microsoft, Adobe Systems, and Intuit are also R&D leaders. US ICT firms dominate the top 50, with notable exceptions such as Nintendo (Japan), Advantest

Table 1: Top ICT R&D spenders: Absolute expenditure, 2006 and 2007 (US dollars, millions)

Rank	Company	Country	Industry	R&D 2006	R&D 2007
1	Microsoft	United States	Software	6,584	7,121
2	Siemens	Germany	Electronics & components	6,312	n/a
3	Samsung	Korea, Rep.	Electronics & components	6,004	6,451
4	IBM	United States	IT equipment	6,107	6,153
5	Intel	United States	Semiconductors	5,873	5,700
6	Nokia[1]	Finland	Communication equipment	4,896	n/a
7	Matsushita (Panasonic)	Japan	Electronics & components	4,854	4,909
8	Sony	Japan	Electronics & components	4,675	4,619
9	Cisco	United States	Communication equipment	4,067	4,499
10	Motorola	United States	Communication equipment	4,106	4,429

Source: OECD *Information Technology Outlook* database.

1. From 2007, Nokia consolidates financial information for Nokia Siemens Networks, a joint venture between Nokia and Siemens. Nokia's reported 2007 R&D expenditure of US$7.730 million is therefore not comparable to earlier expenditures.

Table 2: Top ICT R&D spenders: Expenditure growth, 2000–07 (CAGR, based on current US dollars)

Rank	Company	Country	Industry	Growth (%) 2000–07
1	Google	United States	Internet	113.5
2	SanDisk	United States	IT equipment	91.2
3	Research in Motion	Canada	Communication equipment	63.1
4	Lenovo	China	IT equipment	54.0
5	Nvidia	United States	Electronics & components	42.2
6	Infosys	India	Services	39.5
7	Yahoo!	United States	Internet	38.5
8	eBay	United States	Internet	35.2
9	Symantec/Veritas	United States	Software	34.6
10	Jabil Circuit	United States	Electronics & components	33.6

Source: OECD *Information Technology Outlook* database.

(Japan), ASM Lithography (the Netherlands), Samsung (Korea), LG Electronics (Korea), Qimonda (Germany), Nortel Networks (Canada), Nokia (Finland), and Ericsson (Sweden). Few other European or Japanese firms are among the top 50.

Trends in R&D intensity

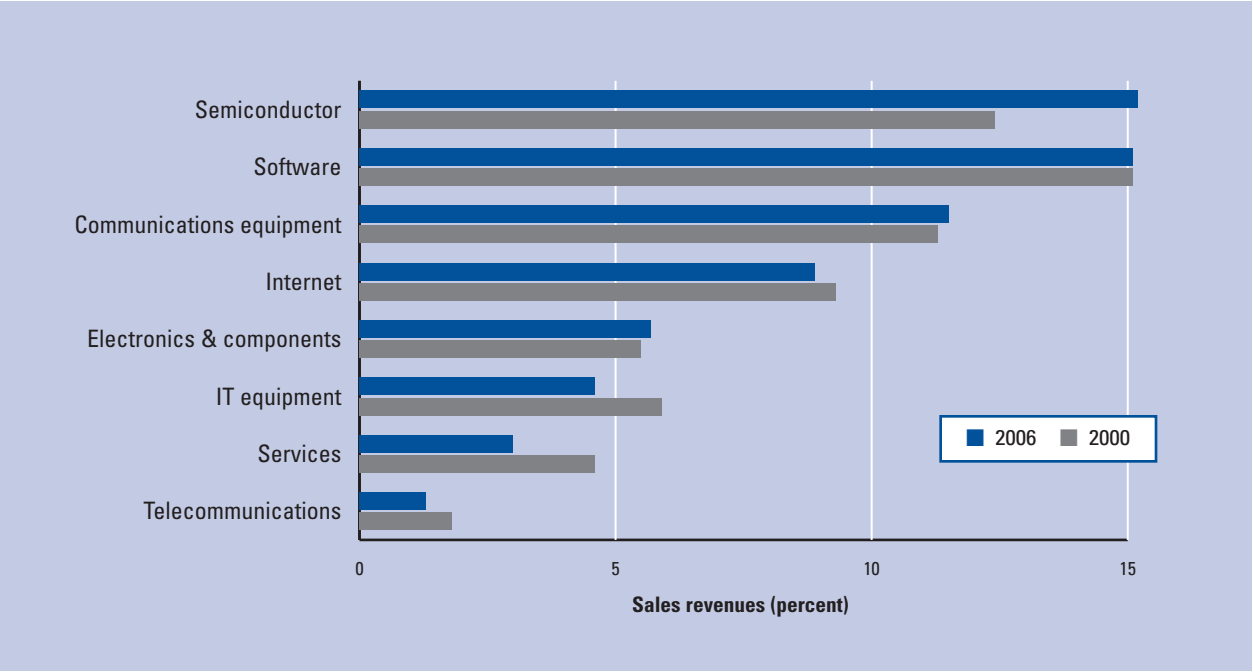
R&D expenditure as a share of sales revenues is another measure of R&D intensity. Semiconductor firms lead by this measure (Figure 6). The top 10 firms in this ranking spent between one-fifth and one-third of their revenues on R&D.

On average, in 2006, semiconductor and software firms were the most R&D-intensive, with average R&D spending equivalent to around 15 percent of revenues. Semiconductor firms had a strong increase in R&D intensity between 2000 and 2006, while IT equipment, services, and telecommunication firms have seen an overall decrease.

IT equipment firms such as Apple, Dell, and Hewlett Packard are often seen as leading innovators, but with R&D intensity below 5 percent they are at the lower end of the top 100 ranking of this variable. Apple's very strong revenue growth, coupled with slower increases in R&D, have led to declining R&D intensities in recent years (3.3 percent in 2007), even though the company is well known for product innovations, leading design and strong branding. Other IT equipment firms with strong consumer product operations from Chinese Taipei and China such as Benq/Qisda, Lenovo, ASUStek, and Acer are also at the lower end of the ranking in R&D intensity, but they tend to innovate most in process technology and supply arrangements. Internet firms such as Amazon and Expedia have stronger R&D intensities (over 5 percent), but they are still far from other US Internet firms such as Google (13 percent) or Yahoo! (16 percent).

Firms from the United States dominate the list of the most R&D intensive. Only one Japanese firm—Advantest (IT equipment)—has been in this top 50 for some years, and some other Japanese companies (e.g., Rohm, Pioneer, Omron, Yokogawa Electric) have oscillated between 50th and 60th place. There are two Chinese communications equipment firms (ZTE and Huawei) in the top 50 most R&D-intensive ICT firms, sharing leading positions with firms such as Juniper

Figure 6: Average R&D intensity of top ICT firms by sector, 2000 and 2006



Source: OECD *Information Technology Outlook* database.

Networks, Tellabs, Qualcomm, Motorola, Avaya, and Cisco (all from the United States); Nortel Networks, Research in Motion (both from Canada); Ericsson (Sweden); Alcatel-Lucent (France); and Nokia (Finland).

ICT-related R&D in other industries

ICT-related R&D is increasingly crucial to technological advances and innovation in non-ICT sectors and products. These include space, defense, infrastructure (e.g., power grids), automobiles, automation, robots, logistics, aviation, health care, environment monitoring, and toys.

A large share of the R&D in non-ICT industries—about one-quarter of economy-wide total ICT R&D—leads to ICT products. Moreover, in some non-ICT sectors, expenditures on R&D that result in ICT products are a large share of total R&D expenditures.[11] Data for European countries show that in the Czech Republic, around 25 percent of ICT R&D in 2006 was performed in non-ICT industries. In Denmark, close to 20 percent of business ICT R&D in 2005 was conducted in non-ICT industries, and in Norway, around 25 percent of ICT R&D was performed outside the ICT sector in 2006.

Within the Asia-Pacific region, in 2006 Japan spent US$5.5 billion on ICT-related R&D activities outside the ICT industry, or 24 percent of economy-wide ICT R&D spending (Figure 7). The biggest share was in transport equipment, which is dominated by the country's carmakers and suppliers, and in electrical and general machinery manufacturing. In Australia, non-ICT-industries were responsible for over 60 percent of all ICT R&D expenditure in 2005–06. Finance and insurance represented 34 percent, largely owing to in-house R&D of large Australian banks.

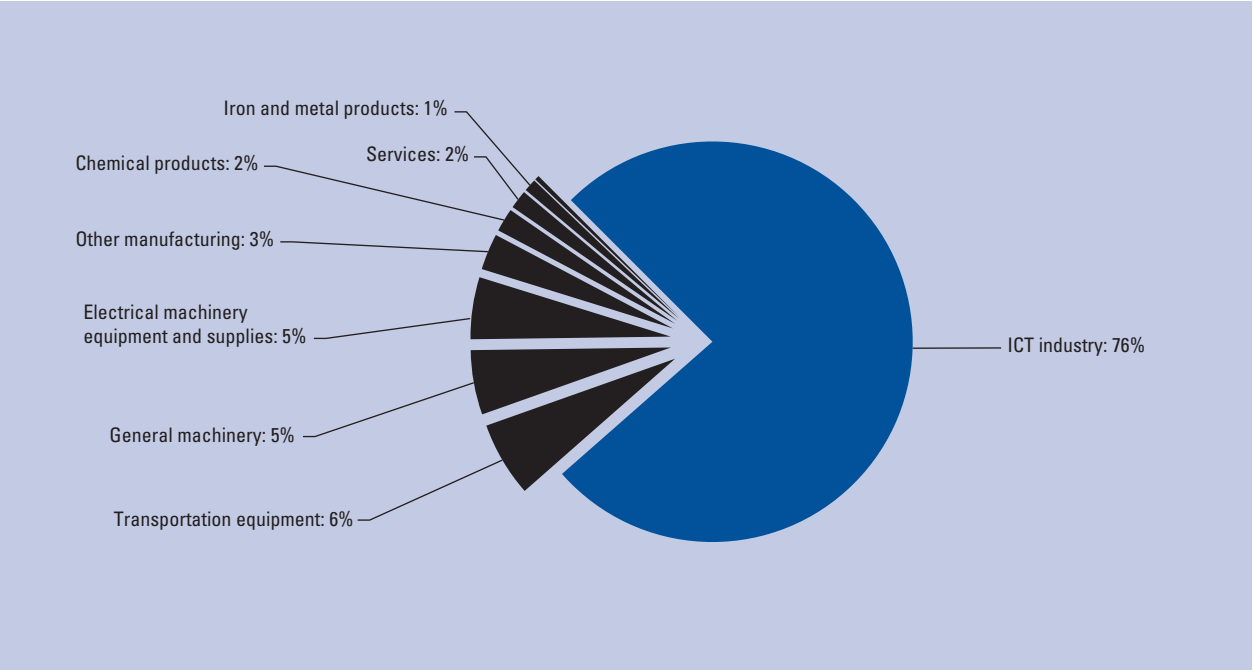
Software development plays a particularly important role in ICT R&D expenditures of non-ICT industries, notably in finance and publishing, but also in manufacturing (e.g., machinery). For example, in the United States in 2005, about 30 percent of software was developed by non-ICT industries—in the chemical, finance and insurance, automotive, and real estate sectors; in other manufacturing activities; and in service activities such as newspapers and architecture.

Trends in the organization of an increasingly globalized ICT R&D

The ICT sector is R&D-intensive but is also innovative in terms of how it organizes R&D. It has benefited from partnerships with public research and employed a mix of internal and external as well as national and international R&D strategies. While all have been used for many years, the organization of R&D has been changing: collaboration and internationalization of R&D are seen as major sources of innovation for the industry, and there are signs that they are increasing.

In recent years OECD countries have substantially raised their overall public funding for R&D.[12] Data on government budget appropriations or outlays for R&D (GBAORD) show that between 2000 and 2006, gov-

Figure 7: Japanese ICT R&D expenditures, in ICT and non-ICT sectors, 2006



Source: Japanese Statistics Bureau, 2007.

ernment R&D budgets in the OECD area expanded by 6.8 percent annually, faster than GDP, although with considerable differences among countries. Because of the complex interactions among research, development, and innovation, the ICT sector has always relied heavily on publicly funded R&D and on partnerships involving government, public-sector research organizations, industry, and universities for long-term basic scientific research. ICT firms are often part of regionally concentrated clusters or set up labs close to universities to benefit from spillovers of public ICT-related R&D. The relative importance of access to public research results increases in times of falling company budgets for basic research.

Globalization of ICT R&D

The internationalization of R&D is not a new phenomenon, but it is occurring at a much faster pace today. Moreover, it is spreading more widely—to emerging economies as well. In most OECD countries, the share of foreign affiliates in industry R&D is growing as foreign firms acquire local R&D-performing firms (e.g., through mergers and acquisitions) or establish new subsidiaries. Along with the pharmaceutical, biotechnology, chemical, health, and automotive sectors, the ICT industry has considerable foreign R&D investment. ICT firms and public research organizations have increasingly internationalized their activities and are establishing R&D laboratories in, or links with, foreign locations, including in non-OECD countries. The ICT sector thus follows the trend of globalizing R&D activities as multinational enterprises more and more aim at exploiting globally available knowledge and skills.[13]

Yet the available data that are produced with long time lags show that most ICT firms still conduct the majority of their R&D in their home country. In 2005, around 12 percent of business ICT R&D in the OECD was under foreign control, and most international R&D relationships were among affiliated companies rather than between domestic and foreign-owned ICT firms or laboratories. Moreover, the R&D intensity of affiliates abroad is generally far lower than R&D intensity in the home country. The need for secrecy, the strong network effects, the search for spillovers, and the high costs of dispersed R&D centers favor concentrating R&D activities in a few places.

Outside the home country, ICT-related R&D investments are generally within the OECD area, with Japanese and European ICT firms mostly establishing R&D centers in the United States, and US ICT firms mainly establishing centers in Europe and increasingly in Asia (see Box 1). Japan and Korea attract comparatively little foreign ICT R&D.

More recent data, however, would show the rapid increase in internationalization that has occurred since 2005. Globalized business ICT R&D networks now involve leading firms such as Cisco, HP, IBM, Nokia, Motorola, Toshiba, NEC, Microsoft, and Google, which are likely to have between five and ten global ICT research centers. A quarter of Samsung's workforce

Box 1: R&D activities of US affiliates

US-based non-bank multinational enterprises (MNEs) have more than doubled the value of their overseas R&D activities through their foreign affiliates since the mid-1990s, to US$28.3 billion in 2005 or around 15 percent of total R&D expenditures of US MNEs (home and abroad).[1] In 2005, seven countries—the United Kingdom, Germany, Canada, France, Japan, and, more recently, Singapore and China—accounted for two-thirds of total R&D performed by US foreign affiliates. The share of R&D in computers and electronic products is about 20 percent of total US MNE R&D abroad—a share that has fallen slightly—but the share of ICT services has increased to around 5 percent of total overseas R&D.

R&D performed abroad by majority-owned foreign affiliates of US parent companies, 2002 and 2005 (current US$ millions)

Industry/sector	2002	2005
All industries	21,063	28,316
Manufacturing	18,736	24,036
Computers and electronic products	4,975	5,376
Non-manufacturing		
Information services and data processing services	24	657
Computer systems design and related services	447	n/a

Source: National Science Board, 2008; Bureau of Economic Analysis, 2007.
Note: Data for Computer systems design and related services for 2005 are suppressed for reasons of confidentiality.
1. BEA 2007, Table 3.6.

(36,000 employees) is involved in R&D with facilities in Korea, India, China, Russia, the United States, and Japan. Global innovation networks also increasingly involve smaller firms.[14]

The internationalization of ICT R&D more and more entails establishing ICT R&D centers in emerging economies. The sector is one of the first to have transformed these into fully fledged elements of globalized research networks. Despite internationalization, R&D activities remain tightly clustered, as in previous national examples.[15] Only a few non-OECD locations are increasingly involved on a larger scale: China (Shanghai and Beijing), Israel (Haifa), India (Bangalore and Delhi), Russia (Moscow and St. Petersburg), and, to a lesser extent, cities in Chinese Taipei, Malaysia, and Singapore.

Affiliates under foreign control continue to devote a smaller share of turnover to R&D than do national firms. However, in contrast to a few years ago when foreign R&D, particularly in developing countries, mainly reflected an investment requirement or the mere need to adapt product for the local market, some foreign research activities now complement headquarter research activities. For example, Hewlett Packard's data mining in Russia, IBM's research on speech technologies in India and embedded systems in China, and Intel/Yahoo!'s software or search technologies in Israel all draw on the local talent pool of domestic firms and research organizations. In addition, ICT firms from emerging markets (e.g., Huawei, Tata) increasingly have their own globalized innovation networks.

Collaborative R&D and "open innovation" on an international scale

The terms *collaborative R&D* and *open innovation* are more and more used to characterize new forms of R&D and innovation that rely less on traditional in-house R&D and more on collaborating on research and innovation with universities, public laboratories, other firms, and other knowledge sources. Major incentives include cost and risk reduction (especially for pre-competitive R&D) and possibilities of entering new markets with jointly developed technologies.[16] Such collaboration is increasingly international and spans across various ICT sectors and adjacent industries (e.g., biotechnology).

Externally organized R&D activities of the ICT business sector have mainly taken the following forms:

- partnerships, framework agreements, or R&D contracts with universities, R&D laboratories, and research institutes, often with a focus on longer-term R&D (including the creation of joint laboratories or high-technology zones by ICT firms on university campuses);[17]
- the involvement of PhD and postdoctoral researchers in the work of company R&D labs;
- R&D partnerships, industrial technology alliances, and consortia of ICT firms (some focused on upstream research and some on product co-development); and
- prospecting for new ideas from individuals and startups with promising research (including through venture capital, incubation and acquisitions, and new participative web strategies).

These trends have strengthened with the greater internationalization of collaboration and the development of global innovation networks. ICT R&D has become more modular and increasingly takes place outside the OECD region. The internationalization of R&D in general is also driven by the growing use of ICT as the basic international science and technology infrastructure (e.g., broadband research networks), by programs that encourage international research collaboration (e.g., the EU's Seventh Framework Programme (FP7) focuses on cooperation with entities from Asian countries) and by

specialized organizations (e.g., the International Technology Roadmap for Semiconductors). Long-standing public research organizations (Fraunhofer ICT institutes in Germany, Battelle in the United States, VTT in Finland, or TNO in the Netherlands) also increasingly form global research alliances or public-corporate R&D consortia.

At the firm level, Asia is becoming the target for new collaboration, both within Asia (e.g., co-development of optical storage media by Samsung and Toshiba) and between OECD ICT firms and Asian partners. Chinese and Indian firms in particular have become strategic research partners for OECD ICT firms (e.g., Siemens and China's Huawei; Ericsson and China's Datang Telecom on alternative 3G network protocols; Agilent and China's Chengdu Qianfeng on communication test equipment; Microsoft and India's Infosys on enterprise resource planning software; Yahoo! and India's Tata on cloud computing). OECD ICT firms also collaborate with Asian universities (e.g., Philips with China's Zhejiang University, US Xybernaut with Beijing University of Aeronautics for software solutions). A few alliances are also forming between Indian and Chinese ICT firms (mainly in the area of software and ICT services) and between Russian and Chinese ICT firms (e.g., Russia's Sitronics and ZTE for global navigation satellite systems).

Besides the new collaboration with Asia at the firm level, R&D partnerships and alliances have encompassed different ICT subsectors, often with links to universities. Semiconductors and microelectronics pioneered such collaboration in the ICT sector in the 1970s. Recent examples include (1) the Reliable Adaptive Distributed Systems Laboratory (RAD Lab) at the University of Berkeley, which is supported by Google, Sun Microsystems, Microsoft, Siemens, Oracle, Cisco and others; (2) RESERVOIR, a research initiative led by IBM in the field of cloud computing, with support from the EU FP7, involving ICT firms from the United States (e.g., Sun Microsystems), the European Union (e.g., SAP, Telefonica), and European universities; (3) Microsoft's and Intel's joint funding of academic research into software development for parallel computing, business intelligence, and radio-frequency identification (RFID); and (4) the joint laboratory for large-scale computer network research formed by the Chinese companies Baidu and Huawei. Collaboration between ICT firms on horizontal topics such as the environment is also more and more common (e.g., the StEP initiative for e-waste).

ICT R&D is also becoming more interdisciplinary, with more research involving nanotechnology, biotechnology, and ICT firms. Such collaboration has not been widely publicized (e.g., Sun Microsystems and SimBioSys for pharmaceuticals; the BioIT Alliance, co-founded by Microsoft, HP, Sun Microsystems, and pharmaceutical and biotechnology companies; Google's investment in 23andMe, a company providing personalized genome analysis).

Finally, a growing number of research partnerships have formed around open standards or common technology platforms. The Open Handset Alliance (formerly Google Android) engages in developing an open source mobile platform: its over 30 members include Google, Broadcom, Intel, China Mobile, KDDI, and Samsung. Further examples of joint handset development platforms include the LiMo Foundation (whose founding members are Motorola, NEC, NTT DoCoMo, Orange, Panasonic, Samsung, and Vodafone) and the joint venture Symbian, which was taken over by Nokia in December 2008 to develop it as a nonprofit organization with many partners in bases in Europe, Korea, Japan, the United States, China, and India. Open source software development and the rising co-development of application interfaces and services are also leading to collaboration and externally focused ICT R&D. The Eclipse Foundation is an open source platform supported by IBM that creates development environments—for example, for enterprise software. Yahoo! partners with the Apache Software Foundation on the development of Hadoop, an open source project for distributed computing and data-intensive applications that is being used for commercial purposes by Amazon Web Services, as well as for research into distributed computing by Yahoo! in collaboration with Computational Research Laboratories (India), IBM, and Google.

In sum, ICT companies increasingly use in-house R&D and their knowledge base (including their intellectual property portfolios) to build more and more complex global innovation networks, to shape global standards, to develop platform strategies, and to access globalizing markets for knowledge workers.[18]

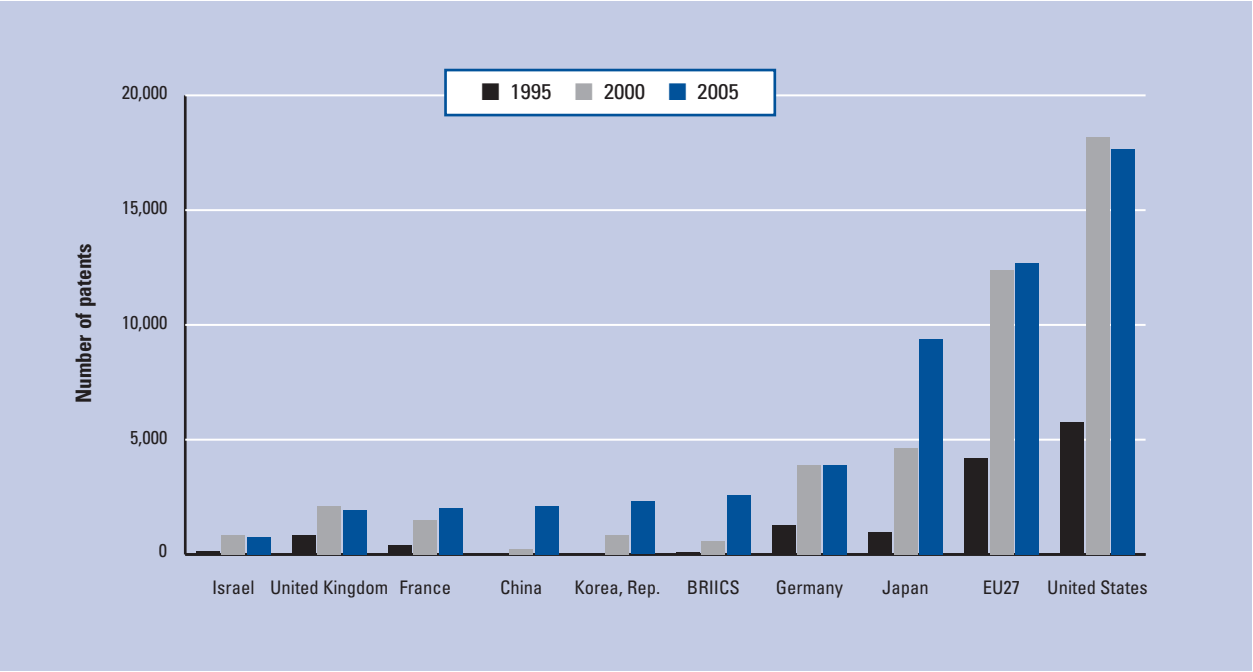
According to Innovation Surveys, the ICT sector is one of the most collaborative sectors after the energy and chemical industries.[19] Among innovative ICT firms in four EU countries, about 34 percent engage in some type of collaboration for innovation (versus 24 percent of all firms), and 13 percent of ICT firms cooperate with universities and public research organizations (versus 8.5 percent of all firms).

In spite of these examples, there are few comparable data on expenditures or on the impact of R&D collaboration and alliances. Some of the available data suggest that ICT firms and institutions have a large array of cooperative activities, particularly of an exploratory nature, but that the competitive dynamics of the industry mean that most development and innovation close to market is still often tightly held within firms. The organization of joint R&D projects continues to raise potential difficulties relating to the sharing of research results and the protection of strategic company information.

Internationalization of ICT-related patents

The number of ICT-related patents grew significantly from the mid 1990s to 2005, when some 50,500 international ICT-related patent applications were filed under

Figure 8: ICT-related patents filed under the PCT, by country, 1994–2005



Source: OECD, Patent database, June 2008.
Note: BRIICS stands for Brazil, Russia, India, Indonesia, China, and South Africa, all of which are OECD accession or enhanced engagement countries.

the Patent Co-operation Treaty (PCT) with an average increase of 16 percent a year (CAGR) over 1995–2005.[20] From 2000 to 2004, ICT was the third fastest growing technical field among PCT international applications (an increase of 28 percent), behind medical (up 32.2 percent) and audiovisual technology (up 28.3 percent).

The United States, Europe, and Japan continue to lead in terms of total PCT applications (Figure 8). The number of ICT-related patents grew considerably in Korea and in China, with 2,308 and 2,099 international patents, respectively, in 2005; Chinese ICT patents more than doubled between 2004 and 2005. Resident ICT patent filings in the home country have grown particularly significantly in Korea and China. The main drivers are Samsung (Korea), LG Electronics (Korea), Huawei (China), Electronics and Telecommunications Research Institute (Korea), ZTE (China), and NHN (Korea).

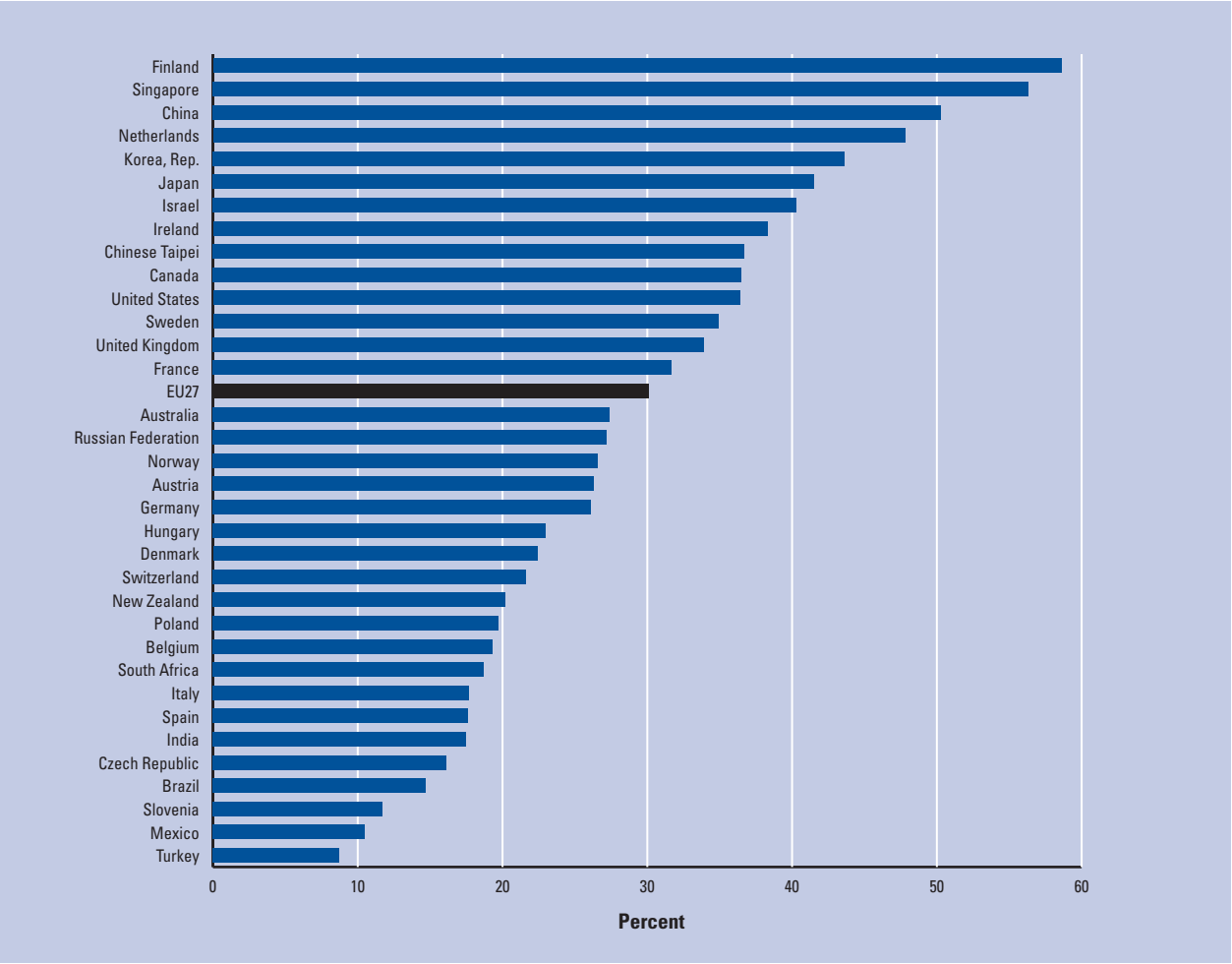
ICT-related patents represent on average 35 percent of total PCT filings, and the share of ICT patents has been rising in almost all countries since the late 1990s (Figure 9). The shares are higher in some countries owing to the focus on ICT inventions in Finland (59 percent of all national PCT filings), Singapore (56 percent), the Netherlands (48 percent), Korea (44 percent), and Japan (41 percent). The proportion of ICT patents in total Chinese filings tripled in a decade, from 17.3 percent in 1996–98 to 50.3 percent in 2002–05. India, Russia, South Africa, Brazil, Chile, and other OECD-enhanced engagement or accession countries are lower, with Israel as the exception. The United States (35 percent of all ICT-related patents), Japan (18 percent), and Germany (8 percent) lead in ICT-related patenting under the PCT and together make up well over half of ICT patent filings. Korea stands sixth, just before China, which is ahead of many other OECD economies.

Patent data also reveal that ICT patents are more internationalized than patents of other sectors: 17.5 percent of all ICT patents granted between 2001 and 2003 involve cross-border ownership.[21] Non-OECD countries such as China, India, Brazil, and Russia still show a high level of foreign ownership in ICT-related patents. Patent data also confirm the growing role of non-ICT industries in ICT R&D and innovation. In Europe, for example, the automotive sector accounted for 4 percent of total software patents.[22]

Clustering on international level is also evident when looking at patent data. Table 3 shows the regional clusters with the greatest intensity of ICT patenting. Next to other regions in the OECD, Japan, the United States, and Korea take up the first spots. China and Israel are now also represented in this ranking.

ICT firms occupy the top positions with respect to patents granted or applications for patents. Patent grants result from applications a few years earlier and are more a retrospective than prospective indicator. As shown in Table 4, 18 ICT firms are among the first 20 firms with patents granted by the United States Patent and Trademark Office (USPTO).

Figure 9: Revealed technology advantage of countries in ICT, 2003–05



Source: OECD, Patent and REGPAT Databases, June 2008; EPO *Worldwide Statistical Patent Database,* October 2007.
Note: Patent counts are based on the priority date and the inventor's country of residence, and use fractional counts on PCT filings at international phase (European Patent Office, or EPO, designations). The figure shows the share of ICT in the country's patents relative to the share of ICT in total patents, by country. Only countries/economies with more than 250 patents over the period are included in the graph.

Table 3: Top 15 regions in ICT-related patents, 2003–05

Region[1]	Country	ICT patents	Share (%) of total
Tokyo	Japan	9,382	6.8
San Jose–San Francisco–Oakland	United States	8,576	6.2
New York-Newark-Bridgeport	United States	4,420	3.2
Capital region (Seoul–Incheon–Gyeonggi-do)	Korea, Rep.	4,412	3.2
Noord-Brabant	Netherlands	3,801	2.8
Boston–Worcester–Manchester	United States	3,579	2.6
Kanagawa	Japan	3,390	2.5
San Diego–Carlsbad–San Marcos	United States	2,788	2.0
Osaka	Japan	2,701	2.0
Los Angeles–Long Beach–Riverside	United States	2,687	2.0
Île de France	France	2,424	1.8
Oberbayern	Germany	2,295	1.7
Shenzhen–Guangdong	China	2,033	1.5
Seattle–Tacoma–Olympia	United States	1,998	1.5
Israel	Israel	1,974	1.4

Source: OECD, Patent and REGPAT Databases, June 2008 (see also OECD, 2008f); EPO *Worldwide Statistical Patent Database,* October 2007.
Note: Patent counts are based on the priority date and the inventor's country/region of residence, and they use fractional counts of PCT filings at international phase (EPO designations).
1. The regional breakdown is presented at EU's Nomenclature of Units for Territorial Statistics (NUTS) level 2, except for Japan (NUTS 3), the United Kingdom (NUTS 1), and the United States (TL 3). In this breakdown, smaller countries such as Denmark and Israel are treated as regions.

Table 4: ICT firms among the top 20 patenting firms, 2007

Rank	Firm	Country	Number of patents
1	IBM	United States	3,125
2	Samsung	Korea, Rep.	2,723
3	Canon Inc	Japan	1,983
4	Matsushita Electric Industrial	Japan	1,910
5	Intel	United States	1,864
6	Microsoft	United States	1,637
7	Toshiba	Japan	1,519
8	Micron Technology	United States	1,476
9	Hewlett Packard	United States	1,466
10	Sony	Japan	1,454
11	Hitachi	Japan	1,381
12	Fujitsu	Japan	1,293
13	Seiko Epson	Japan	1,205
15	Infineon Tech AG	Germany	847
17	Texas Instruments	United States	749
18	Ricoh	Japan	727
19	Siemens	Germany	698
20	LG Electronics	Korea, Rep.	682

Source: USPTO, 2008.
Note: The USPTO does not publish patent applications but patents granted. Figures show the total number of patents granted to these firms, in all industries, and not only ICT-related patents

The majority of the top 20 patent applicants in Europe, Japan, and under the PCT are ICT firms: 13 out of 20 in Europe, 14 out of 20 in Japan, and 16 out of 20 under the PCT.[23] No ICT firm from outside the OECD region or from OECD accession/enhanced engagement countries is in the top 20 firms granted patents in the United States or among the top 20 applicants at the European Patent Office (EPO) or the Japan Patent Office (JPO). The picture is different for applications under the PCT. Whereas Huawei occupies slot number 93 at the EPO (1,365 applications in 2007, according to Eurostat 2007), it is in fourth position for PCT patent applications.

Patent applications rose by 41 percent from 2006 to 2007 at the Chinese patent office (SIPO), owing in large part to ICT applications (mainly for communications equipment). Huawei, with 1,544 applications, ranked first in 2007. Four out of ten patent applications came from foreign entities, with firms from Chinese Taipei among the top ten applicants. Samsung was the leader in foreign patent applications in China. Matsushita Electric Industrial, Philips, and IBM were also among the leaders.

Strong growth in ICT sector patenting is first and foremost a result of high R&D expenditures and the innovative nature of the ICT sector. It also reflects the trend toward more patenting, new ICT subsectors, patenting by non-OECD ICT firms, and the rise of new forms of patenting—for example, of software or business methods in certain OECD countries. Additional drivers are strategies to take out multitudes of patents (so-called patent thickets) or to bring technologies to market; interest in licensing technologies, including by firms specializing in patenting; the desire to ward off patent disputes; and the building of a domestic technology base to avoid paying royalties.

The ICT sector has also played a leading role in post-R&D alliances, product innovation, and other innovation related to intellectual property. ICT firms have long been, and are increasingly, engaged in strategies involving, for example, technology cross-licensing (including to competitors), the creation of patent pools (e.g., the MPEG-2 patent pool), patent clearinghouses, and the granting of patents to wide communities of users (e.g., IBM). These commercial exchanges of intellectual property allow for combining patented technologies from various sources into new products, for potentially avoiding patent disputes, and for facilitating product innovation at lower costs.

However, the overall impact of increased patenting and of new intellectual property alliances on innovation and the patent system remains unclear. Patent data need to be complemented by research that seeks to establish better patent quality indicators and links with the measurement of innovation.

Conclusion

The ICT industry leads in R&D expenditures, employment, and patents; the software and semiconductor sectors are particularly R&D-intensive. The share of ICT R&D conducted in non-ICT industries is also high (about one-quarter of total ICT R&D), and in some non-ICT sectors, ICT R&D spending (especially software-related) accounts for a large share of total R&D. The United States and Japan still have a large lead in terms of ICT firms' R&D expenditures and of ICT firms that spend the most. Korea has caught up impressively in this area. Although some other OECD and non-OECD countries also have relatively high levels of ICT R&D spending, ICT R&D expenditures from non-OECD ICT firms (especially from China and India, but also other emerging economies) are still comparatively low. However, new ICT firms from non-OECD countries are emerging rapidly, are increasingly R&D-intensive, and are rapidly forging new partnerships with OECD ICT firms and research organizations.

The organization of R&D in the ICT sector continues to evolve, in particular around new kinds of collaboration involving emerging ICT subsectors or common standards and technology platforms. The sector's research activities are increasingly international, although ICT firms commonly form global R&D networks with a limited number of R&D centers located in only a few locations. Moreover, the reliance on long-term ICT-related public R&D and public-private collaboration continues to be important for the ICT sector. There has been a striking growth in the number of ICT patents from the OECD region (in particular from Korea) but

also from non-OECD ICT firms (e.g., some Chinese firms). The impacts of this patent increase—that is, whether this increase spurs or deters innovation—merit more study.

Notes

1 OECD work on ICT R&D and innovation is conducted in the recently published *OECD Information Technology Outlook 2008* and in the context of the OECD Innovation Strategy (www.oecd.org/innovation/strategy). The topics of globalization of R&D activities and open innovation are elaborated in more detail in OECD 2008a, b, c, and d. The OECD develops the guidelines for international measurement of R&D, innovation, and patents. See OECD 2002, 2006, 2008e.

2 OECD 2008a.

3 The BRICS countries are Brazil, Russia, India, China, and South Africa.

4 The OECD 21 countries are Austria, Australia, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Korea, the Netherlands, Norway, Poland, Portugal, Spain, the United Kingdom, and the United States.

5 The EU15 countries are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom.

6 See also Jaruzelski and Dehoff 2007.

7 In compliance with the policies of the authors' institution, this chapter exceptionally employs OECD's terminology for Taiwan, China.

8 In May 2007, OECD countries agreed to invite Chile, Estonia, Israel, Russia, and Slovenia to open discussions for membership in the Organisation and offered enhanced engagement, with a view to possible membership, to Brazil, China, India, Indonesia, and South Africa. The approval of "road maps" in December 2008 marks the start of accession talks with Chile, Estonia, Israel, Russia, and Slovenia. See http://www.oecd.org/document/33/0,3343,en_2649_34487_38603809_1_1_1_1,00.html.

9 OECD 2009.

10 See OECD 2006.

11 Not considered is ICT research that leads to non-ICT products that can also be identified in product-field data.

12 OECD 2008a.

13 Wunsch-Vincent 2000; OECD 2008a, 2008c.

14 Ernst 2008.

15 In the United States, for example, 70 percent of the R&D performed by all domestic and foreign computer and electronic firms in 2005 took place in four locations: Cambridge and Route 128 in Massachusetts; the Silicon Hills of Austin, Texas; Champaign County in Illinois; and Silicon Valley in California.

16 Freeman and Soete 2007.

17 Examples of partnerships with universities include Oracle and the European Organisation for Nuclear Research (CERN) for grid-computing technologies; Microsoft, Nokia, Hitachi, and Toshiba with research centers at the University of Cambridge; and Fujitsu with the Universities of Tokyo and Cambridge on quantum technologies.

18 Ernst 2008; Dedrick and Kraemer 2008.

19 OECD, based on the Fourth European Community Innovation Survey (CIS4).

20 See OECD 2008c.

21 OECD 2008c.

22 Hall et al. 2006.

23 See OECD 2008e for methodology.

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