The Innovation Imperative
Contributing to Productivity, Growth and Well-Being

Chapter 5

Knowledge creation, diffusion and commercialisation

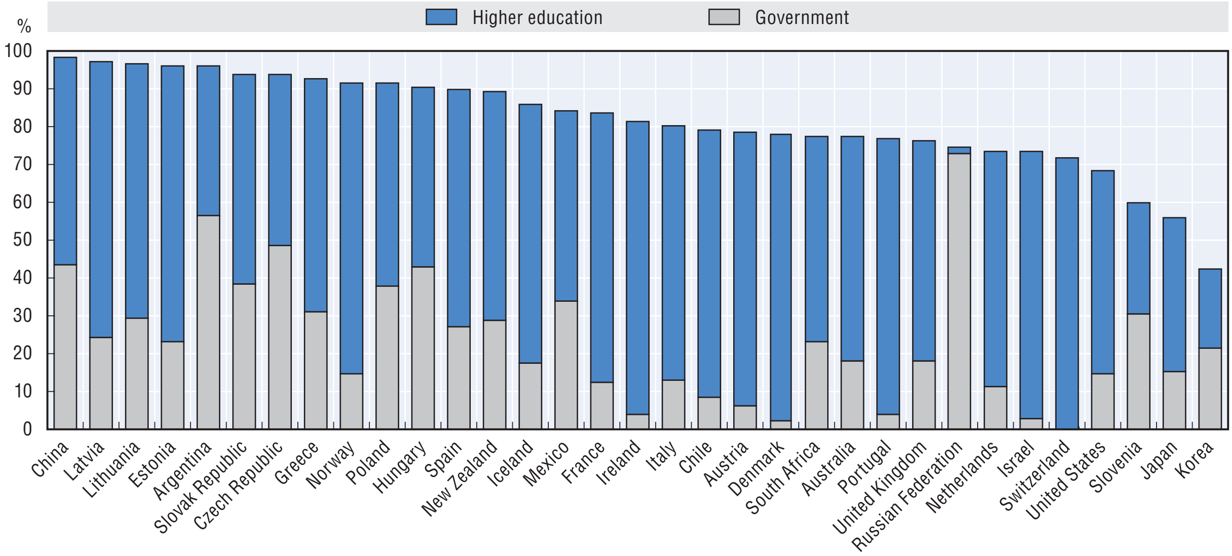
Policies for innovation *also require a strong and efficient system for knowledge creation and diffusion that engages in the systematic pursuit of fundamental knowledge, and that diffuses this knowledge throughout society through a range of mechanisms. This chapter reviews policies on: the science system, including the promotion of research excellence and the role of open science in increasing the economic and social returns to public investments in scientific research, as well as the role of international co-operation in science and technology; emerging practices in commercialising publicly funded research trends; policy issues relating to the interconnected themes of ICT, "big data" and the open Internet; the evolving relationship between IPRs and innovation; and the development and functioning of knowledge networks and markets.*

5.1. Science and public research

As described in the 2010 Innovation Strategy (OECD, 2010a), while the relationship between science and innovation is complex, public investment in scientific research is widely recognised as an essential feature of effective national innovation systems. Public research plays a key role in innovation systems by providing new knowledge and pushing the knowledge frontier. Universities and public research institutions (PRIs) often undertake longer-term, higher-risk research and complement the research activities of the private sector. Although the volume of public R&D is less than 30% of total OECD R&D (OECD, 2014a), universities and PRIs perform more than three-quarters of total basic research (Figure 5.1).

Figure 5.1. **Basic research performed by the public sector, 2012 or latest available year**

As a percentage of total basic research



Note: The higher education sector may include private organisations, e.g. university hospitals, in some countries. For Chile, China, Norway, the Russian Federation, Spain and the United States, basic research expenditure covers only current costs.

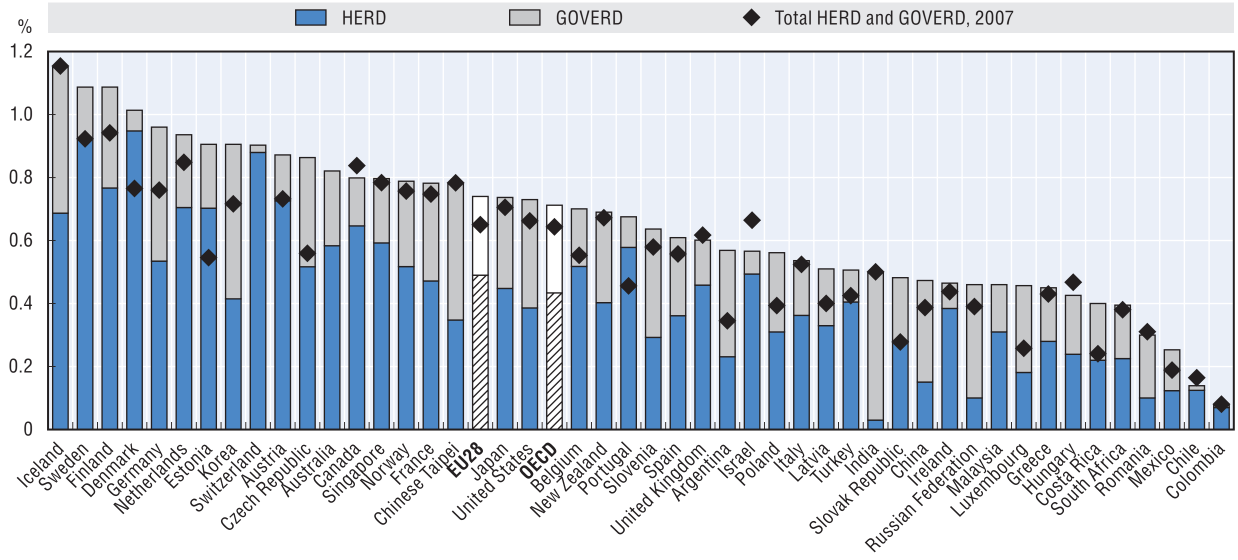
Source: OECD (2014a), *Science, Technology and Industry Outlook 2014*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/sti_outlook-2014-en*.

Basic research is particularly important, as it gives rise to significantly larger knowledge spillovers than applied research while making applied research much more productive (Akcigit, Hanley and Serrano-Velarde, 2014).[1] The history of science shows that many of the great breakthroughs resulting from scientific research were regarded as significant only in hindsight (Kirschner, 2013). They were not the result of a focused effort to achieve a specific impact, but instead reflected serendipity. Ensuring a balance between basic research, driven by excellence, and more focused, mission-oriented research is therefore an important challenge for public funding.

The immediate economic returns from investment in academic research have not always been easy to demonstrate,[2] although there is much evidence that many of the most important innovations over the past decade have their roots in public research, including the Internet and genomic technologies. In many OECD countries, there has been pressure on public funding for research over the past five years as a result of the economic crisis. Nevertheless, relative to GDP, public spending of R&D has held up quite well in most OECD countries since the crisis (Figure 5.2)

Figure 5.2. **Public R&D expenditure by type of research system**

HERD and GOVERD, as a percentage of GDP, 2012, and total HERD and GOVERD in 2007



Note: HERD: higher education R&D; GOVERD = government intramural R&D.

Source: OECD (2014a), *Science, Technology and Industry Outlook 2014*, *http://dx.doi.org/10.1787/sti_outlook-2014-en* based on OECD (2014b), *Main Science and Technology Indicators 2014-I*, *http://dx.doi.org/10.1787/msti-v2014-2-en*.

Three key science-related trends and areas of policy interest were identified in the Innovation Strategy. These related to: 1) institutional financing mechanisms and promotion of multidisciplinary research; 2) the quality and relevance of research and research assessment; and 3) commercialisation, creation of spin-offs and support for centres of excellence. In addition, the shift towards open science was noted, and in this connection, access to research information and data resulting from public funding were highlighted as areas in which policy intervention would be useful.

The 2014 publication *Promoting Research Excellence: New Approaches to Funding* (OECD, 2014c) addressed all three of the above-cited areas of science policy interest. This work focuses on research excellence initiatives (REIs) and draws on the results of surveys completed by government research funding agencies, centres of excellence and their host institutions. The principal findings were that:

- National research systems face an increasingly competitive environment for ideas, talent and funds. The emergence of world rankings of university performance reflects such competition.[3] Governments have thus turned to more competitive forms of funding to promote efficiency and innovation. Among other steps, governments have shifted funds from institutional core funding to project funding, often on a competitive basis.

But research also requires a degree of funding stability, which is made difficult by an exclusive reliance on competition. REIs have emerged against this background. Today, over two-thirds of OECD countries operate REIs.

- REIs are designed to encourage outstanding research by providing large-scale, long-term funding to designated research units. They fund research, physical infrastructure, training, co-operation between research and industry, and the recruitment of outstanding researchers. The single most important goal is to increase national research and innovation capacities. Some countries operate a single REI while others have several. The average funding cycle is around six years. Such funding stability is especially important for new fields of research that might lead to significant scientific developments, but which are otherwise risky and difficult to develop through short-term project funding.
- Most REIs share the following traits: government funding of selected research units and institutions; exceptional quality in research and research-related activities; long-term funding (a minimum of four years); competitive funding distributed on the basis of peer-reviewed applications; funding applications made by institutions or research units (instead of individuals); and substantially larger funding than for project-based activities.

A first observation on the impact of REIs is that rigorous evaluations are lacking both of REI outputs and of how REIs affect broader dimensions of welfare. The available evidence mainly takes the form of expert opinion. However, multiple such accounts suggest that REIs have often been able to:

- promote excellence in research by providing researchers with better opportunities to work across disciplines than exist in many other research contexts
- bring exceptional researchers together in well-equipped working environments to open new lines of research, establish new interdisciplinary research and develop human capital
- raise the international reputation of domestic research institutions
- form long-term international linkages, in part by recruiting leading foreign researchers
- positively affect institutions not selected for funding by triggering intensified co-operation between traditional disciplinary departments and new interdisciplinary research initiatives.

A number of policy-relevant questions remain. For instance, what is the optimal balance among institutional, project and REI funding? The answer to this question may be case-specific and impossible to give unequivocally with existing data, but comparative qualitative research could provide important insights. Whether an REI is best used as a temporary tool to strengthen the research system or whether it should be institutionalised as part of the funding portfolio is not clear. If used as a temporary tool, the question arises of how to maintain excellence once REI funding ceases. But if REI funding is institutionalised, it is unsure whether constant competition for excellence status will improve system performance over the long term.

Looking to the future, many OECD countries are increasing their investment in research aimed at addressing global challenges. This raises issues of governance, including at the international level (see Chapter 8), but also highlights the need for new interdisciplinary and trans-disciplinary research environments that bring together diverse natural and social scientists. Such collaborations can be difficult to establish in traditional university settings, with their embedded disciplinary structures. It would be timely to analyse existing initiatives to assess which arrangements are most effective in bridging disciplinary barriers.

In order to evaluate the quality and relevance of publicly funded research, various forms of research assessment have been introduced in most OECD countries. In this regard, OECD (2010b) aimed to take stock of thinking and practice around performance-based funding for public research in tertiary education institutes (TEIs). Such funding involves *ex post* evaluation of research outputs and outcomes from universities and other tertiary institutions, and is generally based on peer review, bibliometric or other quantitative indicators. The results inform government decisions on which institutions to fund and how much funding they should receive.

In most countries some form of performance-based research funding (PBRF) has been introduced over the past two decades. Funding rounds are either annual or multi-year. The overall range of indicators of research outputs and outcomes used is similar across countries, although combinations and weightings differ.

In general, peer review is used for individual and departmental evaluations, while quantitative formulas (with or without additional peer review) are used for university-level evaluations. The direct and indirect costs of assessment can be large, but this is rarely discussed in the literature. While the amounts of money subject to PBRF may be small, the incentive effects could be strong, particularly if the results affect institutional prestige or access to other research funding.

The science community is still trying to define the meaning of "quality" in research outputs as well as the relationship between outputs and their impacts. All of the routinely used measures – from citation indices to patent numbers – are proxies for performance. In addition, the integration of innovation and research policy has given rise to new indicators of knowledge transfer and commercialisation. The rapid move towards open science is also likely to require new indicators for assessment, such as citations for databases.

Formal evaluations of PBRF are limited, but the available evidence suggests that it has positive effects on research output and management. However, there is intense debate on the intended and unintended consequences of PBRF on science systems. The effect of PBRF will depend on how institutions allocate funds internally, which in turn is affected by their degree of autonomy and internal governance practices. Institutional responses to assessment also differ. For instance, a poor assessment may lead one university to close a department, but lead another to make improvements. Negative effects have also been reported, such as a narrowing of research focus. There is a pressing need for structured studies to assess effects at national, institutional and departmental (and even individual) levels. Such research could be of great benefit to national authorities and universities in their efforts to increase the effectiveness and the efficiency of institutional funding.

Research integrity is an issue that has attracted growing attention over the past five years, and is linked to how research performance is incentivised and measured. Recent high-profile incidents of research misconduct threaten to undermine public trust in science. At the same time, the irreproducibility of some results purporting to be scientific breakthroughs raises questions about the rigour of scientific practice.

Substantial public and private investment in following up on some of this work has been wasted. Pressure to publish, extreme competition, short-term funding and uncertain career tenure are all variously blamed for creating distortive pressures in the scientific system. However, careful analysis of the effects of such factors on academic behaviour is sorely lacking. Some key policy messages related to the science system and its link to innovation are below.

Main policy messages: The science system and innovation

- Funding of basic research remains important for underpinning innovation and for tackling global challenges. Against a backdrop of fiscal consolidation, governments are under pressure to demonstrate social and economic returns from public funding, which calls for science policies that promote excellence, open access and impact.
- Long-term funding for curiosity-driven research must be preserved and project-based funding must be significant in order to allow more direct steering of public research by funding agencies and research ministries.
- Researchers are central to science systems and research careers must remain attractive, while training policies must respond to the increasingly data-driven, co-operative and multidisciplinary nature of science.
- As the role of large research infrastructures in scientific research and research budgets is increasing, sustainable funding and effective governance mechanisms are required.

5.2. Open science: Increasing the return on public investments in scientific research

"Open science" refers to a way of doing science based on unrestricted access to publicly funding research results, namely articles and data. Although associated with public research, open science can also be applied in the business sector and thus enable innovation. Open science also enables the increased engagement of citizens in scientific progress and innovation. Open science requires the interoperability of scientific infrastructure in order to share research results and data. This may involve the creation and long-term support of publication and data repositories, the creation and cleaning of metadata, open and shared research methodologies (such as open applications and informatics code), and machine-friendly tools (allowing, for example, text and data mining). The dissemination of government-funded research results has to date largely relied on scientific journals. However, this model is evolving. The Internet has greatly lowered the marginal cost of online publishing. The costs of data storage and archiving also continue to fall. And advances in computer science are creating opportunities to organise, share and reuse vast amounts of data generated by public research.

Governments and the scientific community have championed greater access to scientific data for a variety of reasons:

- To improve efficiency in science. Open science could increase research productivity by: 1) reducing research duplication and the re-creation of data; 2) allowing a more accurate verification of research results; 3) enabling more research to be done based on the same data; and 4) multiplying opportunities for domestic and global participation in research.

- To generate knowledge spillovers. Increased access to research results could spur knowledge spillovers, innovation and efficiencies across the economy and society.
- To open up new scientific research opportunities. Data-driven science – the exploration of data to generate new scientific hypotheses – has great potential in many areas. Being able to link data across different fields – for instance combining health records with genomic and biological data, or social sciences and environmental data – opens many exciting opportunities.
- To foster the use of public research among SMEs. While larger corporations have the resources to access scientific research results, many SMEs cannot afford potentially useful journals.
- To help address global challenges. Addressing global challenges requires access to and sharing of reliable data from many countries. The international Human Genome Project is an example of a large-scale research endeavour in which an openly accessible data repository has been used successfully by researchers all over the world, for different purposes in different contexts. Furthermore, for scientists in developing countries, greater access to international science and data can help meet social and economic goals.
- To strengthen the evidence base of policy. Public policies and decision making can benefit from scientific data. For example, administrative data from the institutions of OECD member countries, such as employment information, are now used extensively in social sciences and in policy making.

As key funders of public research, policy makers can take a variety of steps to promote access to and the use and reuse of scientific research results. In particular, they can remove barriers to open science by setting appropriate incentives, develop the infrastructure necessary to make open science happen and, in some cases, adopt mandatory rules for open disclosure of publicly funded research results. However, open access is not without costs. Currently, many governments and research institutions are bearing the costs of offering open access to articles and to data as well as the costs of storage and the preservation of data sets online. Given that the volumes of data being generated are increasing rapidly, public institutions will be challenged to find sustainable funding and business models. Public-private partnerships with private service providers may offer innovative solutions.

Universities and public research organisations also have a major role to play by adopting data management policies and ensuring researchers are aware of the IPRs related to scientific articles and data. Scientists often compete to advance science. They therefore have little incentive to share data and experimental material. Mechanisms that acknowledge the publication of data sets and other scientific material on researchers' curricula vitae (CVs) might promote the sharing of scientific information. Providing researchers with the skills to share and reuse data and scientific content in an open science environment is also important.

OECD member and non-member countries are increasingly developing legal and policy frameworks, guidelines and initiatives to encourage greater openness in science, with several countries implementing strategic approaches, e.g. Finland's Open Science and Research Initiative. However, there is heterogeneity in the approaches adopted in different countries and institutions. This is the case, for example, with scholarly publications – while the metadata of a published article are usually made available immediately, regulations on when the full text should be available differ across countries and institutions.

Examples of recent policy initiatives include the following:

- The creation of online repositories, databases, archives and digital libraries and platforms containing information on R&D projects and researchers' CVs.
- Mandatory access: Research funding agencies in many countries – including Australia, Costa Rica, Denmark, Estonia, Finland, Germany, Switzerland, the United Kingdom and the United States – have mandated public access to the results of the research they fund. Other OECD countries are also considering adopting rules for mandatory open access.
- Financial support. Funding agencies in Finland, Germany, Norway, the Netherlands, Switzerland and the United Kingdom have adopted funding mechanisms to cover some of the costs of open access publishing. Elsewhere, governments encourage universities or research organisations to allocate funding for open access initiatives directly.
- Open government data. Open science can also be promoted through the disclosure of government data. A number of OECD member and non-member countries have adopted policies in this respect.
- Modification of intellectual property rules for research or exemptions. Australia and Finland are currently discussing modifications to the existing legal framework for the publication of publicly funded research results to make the copyright legislation increasingly open science-friendly. Germany and the United Kingdom have amended their copyright legislation.

Several studies show that open access publishing improves the impact of scientific papers. Some studies have found a clear – if perhaps unsurprising – correlation between the number of times an article is cited and the accessibility of the same article free of cost online. The impact of open access on business innovation, science and the wider economy needs more extensive assessment. The research that is available suggests that the effects could be large. For instance, Houghton, Rasmussen and Sheehan (2010), estimated that expanding the National Institutes of Health (NIH) open access policy to all other science agencies in the United States could yield a net present value gain of around USD 51.5 billion.[4]

While there are strong arguments in favour of more open science, questions also arise of how the dissemination of lower-quality scientific results can be avoided, and how open access publishing and open data might be made more sustainable through market mechanisms. Indeed, the process of selecting, reviewing and publishing articles in open-access journals is not cost-free, even if it is less expensive to produce than conventionally published literature. In fact, most open access journals rely on subsidies or funding from universities, scientific societies and government agencies. Providing long-term access to quality-assured data is a challenge that is only beginning to be addressed. Some of main policy messages related to open science are incorporated below.

Main policy messages: Open science

The OECD *Principles and Guidelines for Access to Research Data from Public Funding* (OECD, 2007) provide an overarching framework for policy. In terms of scope, the principles and guidelines are meant to apply to research data supported by public funds for the purposes of developing publicly accessible scientific research and knowledge. The full text of the principles and guidelines is available online.[1]

Open science policies should be principle-based but adapted to local realities. For example, if a research project involves business sector partners and commercial interests are present, the requirements for sharing research results may be different from the case in which only public actors are involved. In other cases, privacy or confidentiality concerns may apply to the treatment of certain specific classes of data.

Consultative approaches that involve all relevant actors are key to successful open science strategies. Open science efforts involve different communities and actors. These include researchers, governmental institutions, universities and research centres, libraries and data centres, private non-profit organisations, business sector organisations (including private academic publishers), supra-national entities, and citizens. These actors do not necessarily have the same incentives, goals or expectations. A successful strategy needs to take this diversity into account and react accordingly.

Better incentive mechanisms are needed to promote data-sharing practices among researchers. While all public-sector researchers have an interest in sharing published research articles, the same is not true for research data sets, especially at the prepublication stage. In addition, data cleaning and curation (for example, by developing metadata) is a time-consuming activity that is rarely acknowledged in evaluations or grant allocation procedures. Most evaluations of universities and researchers are almost entirely based on teaching and bibliometric indicators, attributing little value to the sharing of prepublication inputs and post-publication outcomes. Extending citation mechanisms to data sets can partly address this issue.

Clear legal frameworks in relation to the sharing of publications and the reuse of data sets are needed at the national and international levels. A lack of clarity on the interpretation of national and international legal frameworks may prevent the sharing or reuse of research results. In addition, clear guidelines around text and data mining are needed as these tools will be used increasingly by researchers in future.

"Soft factors" such as the development of an open science culture are important. Recent surveys reveal that not all researchers are aware of the possibilities offered by open science. In some countries, different institutions regularly organise workshops and training to make researchers aware of these possibilities. Furthermore, tackling global challenges will require greater access to and the sharing of national public research datasets and hence, co-operation at a global level.

International collaboration is important for open science, especially to address global challenges. International collaboration is becoming more important as publications and data in electronic form cross national borders. Shared and inter-operable infrastructure is necessary to disseminate research results and promote scientific collaboration. Such collaboration can help to share investments and risk, and avoid duplication of effort. International co-ordination and co-operation will grow in importance as R&D and the global production of knowledge shift towards emerging economies. Furthermore, tackling global challenges will require greater access to and sharing of national public research data sets and hence co-operation at a global level.

The impact of open access on business innovation, science and the wider economy needs more extensive assessment, especially where the public-sector costs of openness are significant.

[1] See *www.oecd.org/science/sci-tech/38500813.pdf.*

5.3. International co-operation in science and technology

As described in the OECD Innovation Strategy (2010a), science and innovation are global activities in which multiple actors from many countries simultaneously collaborate and compete. The international landscape continues to evolve, with the BRIICS countries and other emerging economies producing an increasing share of scientific knowledge.

While OECD countries no longer dominate, they are generally maintaining their historical strengths while seizing new opportunities for scientific and technological co-operation. At the same time, in many developing countries science is stagnating. This stagnation undermines efforts to address global challenges.

Over the past five years the OECD has focused on three areas where sound policy is necessary to promote effective international co-operation. These relate to: 1) research infrastructures and networks; 2) global challenges and governance; and 3) promoting co-operation with less-developed countries. The main findings in these three areas of work are summarised below.

International research infrastructures are a major catalyst for scientific co-operation between countries and an essential requirement for scientific progress in some fields, such as physics and astronomy. OECD has worked with science policy makers for more than two decades to improve processes for establishing, operating and assessing large-scale infrastructures. More recently, and spurred in part by moves towards open science and big data, issues around smaller distributed infrastructures have also moved up the policy agenda.

Large-scale science infrastructures can be extremely expensive. The complexities and potential pitfalls in setting up infrastructures are analysed in the 2010 OECD report *Establishing Large International Research Infrastructures: Issues and Options* (OECD, 2010c). While there is no single recipe for success, building on previous experiences and involving those who have this experience is clearly advisable. Empirical assessment of the socio-economic impact of large and long-term facilities is challenging. However, qualitative case studies can give important insights. This is the approach taken in OECD (2014d). This study focuses on the European Organisation for Nuclear Research (CERN) and its most prominent shared scientific facility, the Large Hadron Collider (LHC). CERN is here seen to have impacts far beyond its core scientific mission.

Special challenges affect geographically distributed infrastructures that are often decentralised administratively and financially. Issues relating to the continuity of personnel and funding, legal identity and heterogeneity of partners involved can create difficulties for such shared facilities (OECD, 2014e). One area in which significant progress has been made over recent years is the co-ordination of scientific collections. April 2013 saw the launch of Scientific Collections International (SciColl), a network of museums and other institutions possessing scientific collections. SciColl aims to promote access to these valuable, and often unique, research resources that can provide critical insights in areas as diverse as environmental change, societal development and disease epidemics.

Gauging the impact of large international research infrastructures will continue to preoccupy science policy makers for the foreseeable future. This may be a particularly acute issue for developing countries, where substantial investment in such facilities is a relatively new phenomenon. In this regard, the 2012 agreement to locate an important part of the Square Kilometre Array (SKA) radio telescope in South Africa, with Australia and several other African countries as co-hosts, is groundbreaking. Developing measures to ensure some return to Africa, in terms of scientific capacity and social and economic advances, is in this case an important policy challenge.

If they are to be effectively addressed, global challenges – such as climate change; food, energy and water security; and disease pandemics – require new knowledge and new technologies from science. Responsive and adaptable modes of governance combined with flexible funding and spending mechanisms are essential (OECD, 2012a). A tailored approach to knowledge sharing and intellectual property can be important, and participatory approaches and outreach efforts are indispensable for the successful uptake of innovations. The CGIAR Global Agriculture Research Partnership is one example of how this can be achieved. The inclusion of countries with weaker science, technology and innovation (STI) capacities as full partners is necessary and may require specific actions to build capacities. At the same time, the rapid evolution of open science should provide opportunities for more radical developments in the future governance of STI to help find solutions to global challenges. For example, the recently launched Future Earth initiative has a novel regionally distributed and multi-stakeholder governance and management structure that may provide a new model for the future.

The Ebola pandemic in Africa has highlighted not only the vulnerability to infectious diseases of the poorest countries but also, in a globally connected world, how difficult it can be to contain and effectively treat newly emerging diseases. The development, testing and deployment of new vaccines and therapeutic medicines are essential to the public health response to such outbreaks. In this regard, international clinical trials are critical. In 2012 the OECD Council issued a recommendation on the governance of clinical trials (OECD, 2012b). The recommendation focuses on three areas where policy can help: 1) reducing the administrative complexity of trial processes; 2) introducing a risk-based approach to the approval and management of clinical trials; and 3) improving training, infrastructure and patient involvement.

Natural hazards represent another important global challenge, particularly as more people migrate into urban areas, many of which are located in areas of risk. The Global Earthquake Model (GEM), established in 2009 with the OECD's assistance, is an example of an international science-based response to a natural hazard. GEM is a public-private partnership engaging a global community in the design, development and deployment of state-of-the–art models and tools for earthquake risk assessment. There is potential to expand this type of partnership between scientists and users in other areas of decision making.

In an era of rapidly developing open science, distributed data infrastructures will be critical for science and international collaboration (see the section on open science above). International bioinformatics databases have already played a key role in the development of molecular biology and biomedicine, and international data-sharing is critical for research that addresses global challenges. However, sustainable business models for funding many of these structures are urgently required. While some structures are supported by dedicated core funding, others are largely dependent on competitive short-term grants and/or public-private partnerships. Whatever the mechanism, demonstrating value for money and impact will be an important requirement as the size and number of data infrastructures grows.

The need to include developing countries in scientific initiatives to address global challenges was referred to in the previous section. Achieving this requires specific policy actions. One important area for consideration is the potential synergy between science funding and development assistance. Opportunities exist for science funding agencies and development co-operation agencies to work more closely to strengthen science in developing countries, particularly with regard to global challenges (OECD, 2011a).

Another area in which exchange of practices and experiences between developed and developing countries can be important is in relation to mechanisms and processes for the provision of science advice to governments. Most OECD countries have a variety of formal and informal science advisory structures and individuals that together make up a national advisory system. These national systems are complemented by a similarly diverse set of international structures. Many developing countries have relatively weak science advisory structures. This is an important area for capacity development. International co-operation and/or co-ordination between advisory structures are required, particularly in crisis situations. Some of the main policy messages related to the science system and international scientific co-operation are below.

Main policy messages: International co-operation in science and technology

- Developing effective science and technology initiatives to address global challenges requires responsive and adaptable modes of governance, combined with flexible funding and spending mechanisms.
- International collaboration to build science advisory mechanisms needs to be further developed. Doing so would help to provide reliable and coherent information in crisis situations as well as for meeting global challenges. There is also a need to build advisory capacity in developing countries and to better co-ordinate on common areas of interest across countries.

5.4. Commercialisation of publicly funded research

Publicly financed research in universities and PRIs has led to many landmark technological innovations, from recombinant DNA technology and the Global Positioning System (GPS) to MP3 technology and Siri voice recognition. Increased interest in the commercialisation of public research has various drivers. These include:

- The desire to improve national competitiveness.
- Concern with the fact that the number of patents, licences and companies created at universities and PRIs has slowed since the late 2000s. Indeed, universities face increasing pressure to combine excellence in teaching and research with commercialisation and fund-raising activities. Sweden has even amended its Higher Education Act so as to introduce the building of external partnerships into the mission of higher education institutions to encourage them to actively exploit research outcomes.
- The increasing cost of scientific research, leading many PRIs and universities to search for new funding sources (even if income from commercialisation at most PRIs accounts for a small part of all income).
- A trend towards greater business outsourcing of R&D, with firms increasingly looking to universities and PRIs for much of their basic research.
- An awareness of research that suggests that academic entrepreneurship does not detract from research productivity or lower the disposition to undertake basic research. Indeed, research from Sweden shows that there is a strong positive correlation between scientific excellence and the intensity of industry contacts of individual researchers (Bourelos, Magnusson and M. McKelvey, 2012).

While patents, licences and spin-offs remain important channels for commercialising public research, other channels appear to be increasing in importance. These include collaborative research, student and faculty mobility, contract research, faculty consulting, and student entrepreneurship. ICTs, and a push by science funding agencies for greater access to publicly funded research results and data, are also broadening the channels for commercialisation. OECD (2013a) – *Commercialising Public Research: New Trends and Strategies* – examines recent institutional and policy developments.

Nearly all OECD countries have now adopted specific legislative frameworks and policies to incentivise the commercialisation of public research. Best known among these is the Bayh-Dole Act in the United States, which allowed universities to own the patents arising from federal research funding, and provided incentives for their commercialisation. Bayh-Dole legislation has been widely emulated.

A policy convergence has also occurred whereby in most countries, IPRs are vested with universities. Universities can often overrule national university intellectual property (IP) regulations through university bylaws (for instance to negotiate different IP arrangements with third parties).

Despite the rise of new channels for knowledge transfer in most countries, institutions and policy makers are still focused on promoting commercialisation through patenting and licensing. However, with the exception of a few leading universities and government labs, patenting and licensing are, and will remain, a minor activity for most universities and PRIs. For instance, in the United Kingdom, higher education institutions generated external income of more than GBP 3 billion (British pounds) in 2011/12. However, only 2% to 4% of that amount was from licensing or the sale of shares in spin-off companies. Most of the revenue came from collaborative and contract research, consultancy and professional training (House of Commons, Science and Technology Committee, 2013). Across Europe, only 10% of universities account for around 85% of total licensing income.

There is increasing interest in improving access to scientific research findings in general and, in particular, the results of publicly funded research (see the previous section in this chapter, on open science).

An increasing share of public funding is being directed at co-operative research rather than individual organisations. While universities have long interacted with industry, this has intensified in recent years. Industry and universities (particularly technology transfer offices [TTOs]) can have different perceptions regarding the value of – and sharing of – income from IP. Diverging perceptions can also exist regarding how to share patented knowledge. Inexperience and lack of awareness of business' needs is a common industry complaint (Hertzfeld, Link and Vonortas, 2006). Intermediaries such as IP-based companies or government-backed patent funds are increasingly used to match supply and demand for IP between universities and SMEs.

A range of intermediary and bridging organisations has been created to facilitate knowledge transfer and commercialisation. These include TTOs; business incubators; business innovation centres; science parks; special agencies in chambers of commerce; industry liaison offices (ILO); proof-of-concept centres (which aim to close funding gaps when business angels and VC companies focus on larger or later-stage deals);[5] and libraries/institutional repositories. The missions of these entities can differ considerably, as illustrated in Box 5.1.

The most common goals of TTOs are enhanced licensing revenues, the maintenance or expansion of industrial research support, technology transfer, and, to a lesser extent, regional development. Licensing revenue is typically the most important criterion by which TTOs measure their success, although most TTOs do not generate positive net returns, or break even, from patenting and licensing (Bulut and Moschini, 2009). However, a small number of TTOs generate substantial licensing revenues.

Box 5.1. **Hungary's Innovation Marketplace and the Czech Republic's GAMMA programme**

Hungary – Innovation Marketplace: The National Research, Development and Innovation (NRDI) Office is Hungary's only innovation financing institution, and a center that aggregates all information that might be of interest to actors. It started its work on 1 January 2015 on the basis of the Hungarian Act 2014/XLLVI about scientific research, development and innovation. It is a national strategic and funding agency for scientific research, development and innovation, the primary source of advice on innovation policy for the Hungarian Government, and the primary funding agency.

NRDI is simultaneously contacted by start-ups looking for investors; by technology owners searching for foreign markets; by foreign agencies seeking technologies; by laboratories offering capabilities; and by enterprises needing such capabilities. To help link these different actors, NRDI has developed Innovation Marketplace, which channels all enquiries and turns them into business proposals that are accessible to both governmental and market players. The Innovation Marketplace is becoming a platform that is helping to turn project proposals into standardised business propositions, thus generating the deal flow indispensable for potential investors. Furthermore, the NRDI Office indirectly induces crowdsourcing through the platform, in acting as an intermediary from the state services provider.

Czech Republic – GAMMA programme: The GAMMA programme targets the lack of exploitation of public research results. It aims to support the transformation of R&D results achieved in research organisations into practical applications to enable their commercialisation and implementation. It also promotes co-operation between research organisations and enterprises through "learning by doing". The programme is divided into two sub-programmes:

Sub-programme 1 is aimed at research organisations and supports verification of the practical use of R&D results that were created in research organisations (mainly public) and that should have a high potential for commercial application. It also provides systemic support to identify, implement and develop commercialisation activities in research organisations.

Sub-programme 2 is aimed at supporting applied research and experimental development by enterprises exploiting the research results from public research organisations. Support is provided for projects involving the completion of functional prototypes, verification of their properties, verification of test series, and evaluation of all technological, economic, social, health and other impacts of new products or services. The programme is aimed at enterprises, but research organisations can be project participants.

Many TTOs have expanded their missions from simply administering technology transfer (such as managing invention disclosures, filing patents, etc.) to a range of IP management and support activities (e.g. patent scouts, consulting), marketing non-patent services, administering seed funds, and creating a culture of innovation.

Many universities have sought to reform or replace their TTOs, given their mixed record of success. Alternative models and proposals include:

- **Technology transfer alliances (TTAs):** Given the limited ability of many universities to generate enough income to cover the costs of their TTOs, it has been proposed to share services through TTAs. In theory, TTAs could bundle inventions across universities, lower unit operational costs and increase access to expertise. However, TTAs might raise some co-ordination/communication costs. An example of a TTA is the Innovation Transfer Network (ITN) in the United States. Established in 2006 with public support, the ITN serves as the TTO for 13 smaller colleges, each of which is represented on the ITN's board.

- **For-profit models:** For both cost and efficiency reasons, some institutions have created privately funded TTOs. These take the form of limited liability corporations. Some universities have operated such private TTOs since the late 1980s. (An example is Isis Innovation, a wholly owned subsidiary of the University of Oxford, created in 1988.) In Israel, the majority of TTOs operate under a limited liability model, partly or wholly owned by universities.
- **Internet-based models:** Internet-based platforms can complement existing TTO structures. These platforms respond to the needs of technology transfer professionals and application-oriented researchers for easier access to information. And they help to showcase university technologies to the corporate sector. An example is Flintbox, at the University of British Columbia.
- **A free agency model:** TTOs are sometimes viewed as revenue maximisers reluctant to explore alternative commercialisation paths. This has led to proposals that researchers be allowed to choose between their university TTO or an agent elsewhere (i.e. a free agency model). In theory, this could improve efficiency in TTOs by creating competition. However, reservations exist on the extent to which TTO performance can be enhanced through competition, among other considerations.

While prominent in policy discourse, spin-offs are less prevalent than is often thought. Recent data from the United States' Association of University Technology Managers show that the number of spin-offs per university per year among the top 100 United States research universities is just 2, with a maximum of 22 (at Massachusetts Institute of Technology [MIT]). Spin-off creation varies markedly across OECD countries. On average, Europe has a higher rate of spin-off formation (2.4 spin-offs per USD 100 million of research expenditure during 2004-10) than the United States (1.1 for 2004-11), Canada (1.1 for 2004-11) and Australia (0.7 for 2004-11) (OECD, 2013i).

Research has highlighted the importance of student entrepreneurship, which is being encouraged by universities and governments in many OECD countries. Åstebro, Bazzazian and Braguinsky (2012) show that recent graduates are twice as likely as faculty to create a business and that such firms are often of high quality.

New approaches to financing commercialisation are also emerging. Many universities and PRIs are complementing government funding for university start-ups by setting up their own proof-of-concept and seed funds. But studies point to constraints arising from the lack of business expertise, skills and networks among many academics (Wright, Clarysse and Mosey, 2012). Accordingly, approaches to nurture academic entrepreneurship that focus only on funding gaps may be insufficient.

Case studies show that universities can achieve high levels of entrepreneurial activity through good programme design. This can be the case even when universities have low R&D expenditures, low research/financing capacities and low VC availability (Åstebro, Bazzazian and Braguinsky, 2012).

When universities can override national regulations by developing internal patent regulations and processes, some have experimented with alternative settings. For example, some have provided preferential treatment to researchers wishing to license technologies they have developed. Other universities allow professors to establish new ventures, granting leaves of absence or allowing tenure clock stoppage while faculty pursues commercialisation activities. Of 64 universities surveyed in the United States and Canada, 16 were found to consider patenting and commercialisation achievements in tenure and promotion decisions (Stevens, Johnson and Sanberg, 2012).

Universities in OECD countries also increasingly face the issue of ownership of IP by graduate students and other non-faculty/employees engaged in research. This may give rise to tensions between universities and students. Owing to these changes, and to avoid IP disputes between students and universities, the University of Missouri in the United States established a policy in 2011 that under certain conditions allows students to own inventions created during their enrolment.

National funding agencies and individual institutions have developed standard licensing agreements for academic inventions (e.g. the United Kingdom's Lambert Toolkit, Germany's model R&D co-operative agreements, and Denmark's Schlüter model agreements). Standardised agreements can help address industry concerns of difficulties negotiating licences with PRIs. And some OECD countries have started to sponsor the creation of patent funds specifically for PRIs. Some key policy messages related to the commercialisation of publicly funded research are included below.

Main policy messages: Commercialisation of publicly funded research

A central role for government is to set the basic rules and institutional frameworks that reflect the public interest and provide the right incentives to firms, public researchers and PRIs. In so doing, governments, research ministries and business must work together to develop coherent policy frameworks.

Policy for commercialisation should go beyond the TTOs of universities and PRIs. In most countries, institutions and policy makers are still focused on promoting commercialisation through patenting and licensing. But patenting and licensing are a minor activity for most universities and PRIs. Other channels play important roles. These include public-private collaborative research, student and faculty mobility, contract research, faculty consulting, and student entrepreneurship.

Because many intermediary organisations have arisen as channels for commercialisation, government can help in identifying and disseminating information on best practice.

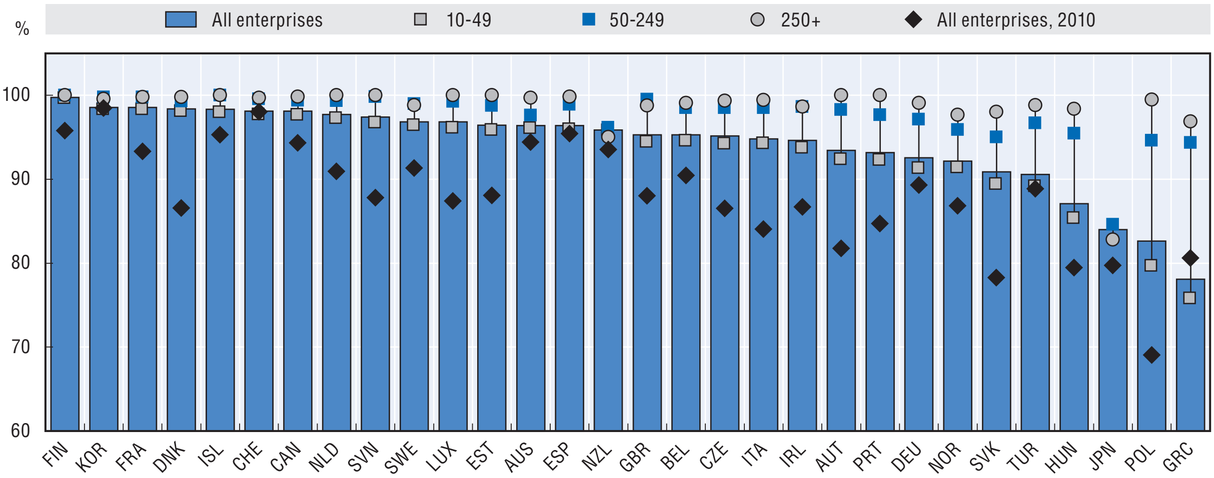
Especially because of digital technology, governments play an increasingly important role in developing the legal frameworks to increase access to and use of scientific research and data.

5.5. ICT, "big data" and the open Internet

Almost no business today is run without the help of ICTs. In 2014, 95% of enterprises in OECD had a broadband connection (Figure 3.13), although with considerable variation among small enterprises (Figure 5.3). More than 75% of all OECD enterprises had a website or a homepage in 2014, up from about 70% in 2009. As for broadband access, web presence is lower among small firms. The speed of adoption depends in some cases on prior uptake. It took 15 to 20 years for slightly more than three-quarters of enterprises to develop a website, but only a few years for around 30% of businesses to become active on social networks.

Figure 5.3. **Broadband connectivity, by size, 2010 and 2013**

Percentage of enterprises in each employment size class



Source: OECD (2014f), *Measuring the Digital Economy*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/888933148520*.

In most cases, a web presence is still used as a window to provide information on the enterprise. Indeed, figures on participation in e-commerce are much lower. On average, 21% of firms with at least ten people employed in reporting OECD countries received electronic orders, 4 percentage points more than in 2009 (Figure 5.4). Differences among countries remain considerable, however, which closely follows the differences in shares of smaller firms among countries. For enterprises with 250 or more employees, participation in e-commerce is about 40%, and the share is above 30% even in some lagging countries. The use of more sophisticated ICT is also less frequent. These include ICT applications used to manage information flows, where implementation requires changes in business organisation, and radio-frequency identification (RFID), where uptake is limited to certain types of businesses.

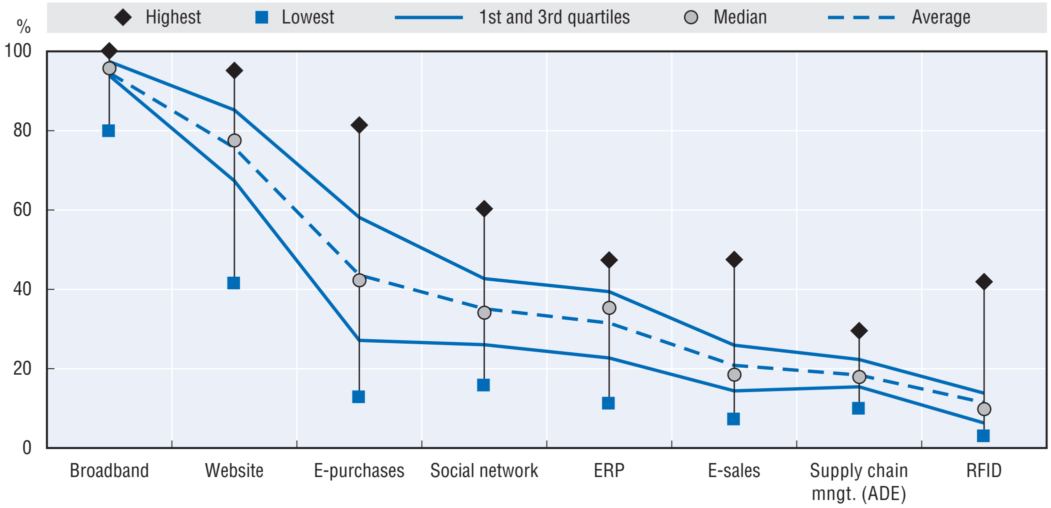
The high level of uptake of ICT across the economy shows how important the technology has become, increasingly, also for innovation. Improvements in the transmission of information have often underpinned innovation. For example, the introduction of telegraphy in the 19th century made railway systems more efficient as speedy communication about the condition of rail tracks allowed many trains to use the same track. The development of information theory in the first half of the 20th century brought the possibility of coherently manipulating data. And the advent of silicon-based integrated circuits, containing billions of transistors, made it possible to apply these theories to information on a previously unimaginable scale. New communications technologies were essential to realising the innovation potential of information technology. Today, the two cannot be seen separately, and "ICT" has become a nearly ubiquitous abbreviation. Around 55% of VC invested in the United States is invested in firms producing ICT-related goods and services. In the past two decades this share has averaged about 60%, with much of the remaining 40% being linked to ICT in indirect ways.

In most OECD countries, information industries[6] account for 20% to 25% of total business expenditure on R&D (BERD) (OECD, 2014f). In Finland, Israel, Japan, Korea and the United States, the sector accounts for 30% to 50% of BERD. It is estimated that across the

OECD, 70% of firms in ICT industries introduce innovations, against an average of 50% for businesses overall (OECD, 2014f). Much innovation in ICTs today is aimed at making data available, through better sensors; communicating those data through various networking technologies; storing data in the cloud; big-data analysis; defining actions through machine learning; communicating those actions; and acting on them through improved actuators (actuators allow a change in physical state, and take many forms, from lasers to ink nozzles to complicated valves operating with magnetic fluid).

Figure 5.4. **The diffusion of selected ICT tools and activities in enterprises, 2014**

Percentage of enterprises with ten or more people employed



Note: ERP = enterprise resource planning; ADE = automated data exchange.

Source: OECD (2015), *Digital Economy Outlook 2015*, OECD Publishing, Paris, *http://dx.doi.org/10.1787/888933224847*.

One way in which ICT underpins innovation is by facilitating the dissemination of knowledge. In some academic fields, such as physics, mathematics and biology, almost all science is first disseminated as a pre-print via arXiv.org. As many as 7 000 preprints are submitted each day. arXiv.org was one of the first examples of the open access movement in science (see the section on open science earlier in this chapter). ICT has also enabled a rapid internationalisation of research. For example, in 1998 only a few countries experienced more than 10 000 international collaborations, but by 2011 this level of international collaboration was common in developed countries.[7] In a further illustration of the knowledge-dissemination effect of ICTs, many universities are putting their courses online. The effect of massive open online courses (MOOCs) is as yet hard to determine but they have the potential to completely revolutionise higher education. Some examples of the impact of ICT on society are included in Box 5.2.

Business models have also changed in response to the possibilities offered by ICTs. For example, today micro-multinationals are common: these are medium-sized enterprises that, despite their size, operate on a global scale. Such firms sometimes have employees and freelancers working around the globe on the same projects, thanks to ICTs. ICT-enabled platforms such as Kickstarter, Indiegogo and Quirky have also given innovators a way of connecting customers and potential investors. By receiving instant feedback through donations and through comments from potential customers, innovators glean an idea of the potential success of their products. Seventy-seven per cent of companies in the OECD have a website, and around 21% sell their products electronically (OECD, 2014f). Over 80% of enterprises use e-government services, with some countries, such as the Netherlands, requiring online filing of taxes for all businesses. Consumers are also pushing companies to change their business models, with as many as 77% of consumers in Denmark, the Netherlands and the United Kingdom purchasing online (OECD, 2014f).

Box 5.2. **Examples of innovation in ICTs affecting society**

In agriculture, ICTs are becoming essential. Dairy farmers increasingly operate automated farms. Robots that feed, milk and clean cows can change the operation of a farm, with these activities being performed to the schedule of individual cows, rather than the farmer's timetable. Geolocation data allow optimal use of fertiliser and pesticide across fields. And greenhouses monitor crops through sensors, but also, because of ICT, can become an integral part of the energy production sector. In the Netherlands, since 1994, greenhouses have entered the energy production market with combined heat power exchange systems that produce warmth and carbon dioxide (CO_2) to grow crops. Such systems reduce the costs of crop production by as much as 20% (Koolwijk and Peeters, 2011).

In transport, vehicles today are a combination of 80 to 200 sensors and processors. Functions such as motor management, anti-lock braking and traction control all rely on information processing. Without ICT's, vehicles would not be as efficient and safe as they are today. And self-driving vehicles promise greater efficiency and safety, as well as increased autonomy for disabled and elderly people. Nissan and Audi expect to sell autonomous vehicles by 2017.

GPS-enabled ICT applications in cars and mobile devices will boost efficiency in transportation systems, yielding significant savings in time and CO_2 emissions. For example, TomTom, a leading provider of navigation hardware and software, has collected more than 9 trillion data points from its navigation devices and other sources. These describe the time, location, direction and speed of travel of individual anonymised users. TomTom now adds 6 billion data points a day. TomTom's data analyses are fed back to its navigation devices to inform drivers of current and predicted traffic conditions. Significant time savings and reduced congestion have resulted, notably in cities. Indeed, the global pool of personal geolocation data is estimated to have grown by 20% a year since 2009. By 2020, this data pool could provide USD 500 billion in value worldwide in the form of time and fuel savings, or 380 megatonnes (million tonnes) of CO_2 emissions saved (TomTom, 2014). The data are also used by governments to understand the effect of proposed and realised infrastructural changes on traffic flows.

5.6. "Big data" analytics

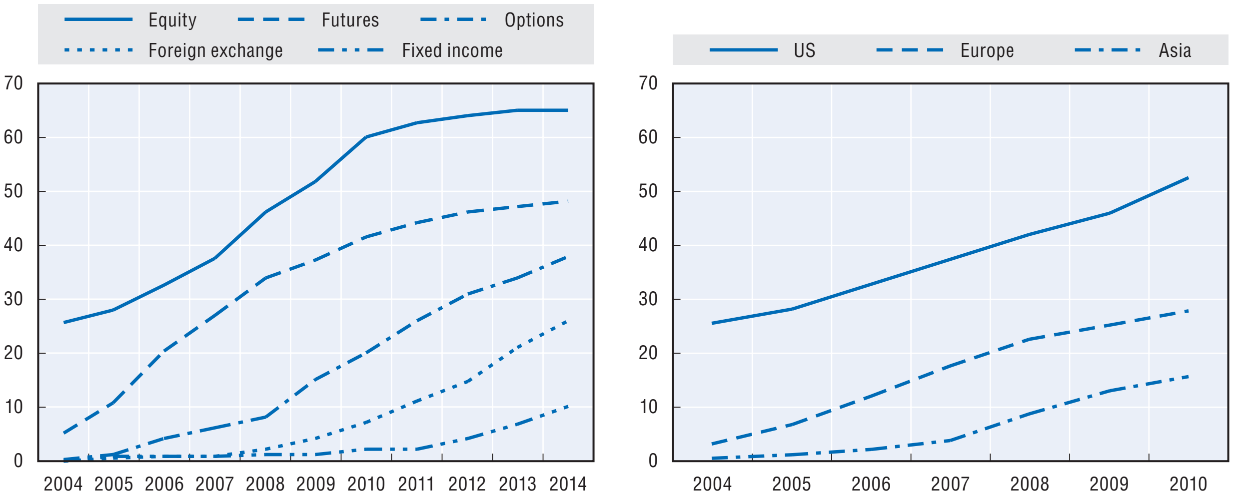
The growing number of computer-mediated transactions and the accelerating migration of social and economic activities to the Internet have led to the generation of a huge volume of (digital) data, commonly referred to as "big data". Big data are now leveraged by organisations, often in highly creative ways, to generate innovations in products, processes, organisational methods and markets. Data and data analytics have become a driving force in innovation. The exploitation of data and data analytics has already created significant economic value for many businesses, and more is expected to follow. A range of studies suggests that the use of data analytics can boost firms' productivity by 3% to 13% (Brynjolfsson, Hitt and Kim, 2011; Bakhshi, Bravo-Biosca and Mateos-Garcia, 2014; Tambe, forthcoming). Some estimates put the global market for big data technology and services at USD 17 billion in 2015, with a growth rate of 40% on average every year since 2010 (IDC, 2012).

Fifty per cent to 85% of all data stored by businesses may be unstructured (Shilakes and Tylman, 1998; Russom, 2007). Data analytics can allow the cost-effective extraction of information from unstructured data sources such as text documents and e-mails, videos, images and audio streams. Furthermore, data analytics has empowered organisations to base their decisions on (near to) real-time data. For businesses, this means reduction of time to market, as well as benefits due to first- or early-mover advantage. And for governments, data analytics can permit real-time evidence-based policy making (Reimsbach-Kounatze, 2014).

As organisations increasingly use data and analytics, a shift can be seen in the way decisions are made, with greater reliance on correlation instead of causation. For example, a company such as Wal-Mart may change the product placement in its stores based on correlations with purchases, without the need to know *why* the change affects consumer behaviour. As Anderson (2008) explains: “Who knows why people do what they do? The point is they do it, and we can track and measure it with unprecedented fidelity.” Anderson (2008) has even challenged the usefulness of model-building in an age of massive data sets, when machines can detect complex patterns in vast databases that are otherwise invisible to researchers.

Data analytics also empower autonomous systems, which use machine learning algorithms to improve performance with every data set analysed. These systems are now becoming mainstream thanks to the widespread availability of large volumes of data. Such systems can perform a growing range of tasks that previously required human intervention. Google’s driverless car is an example of this potential. The car takes data from multiple on-board sensors, including video cameras and radar systems, and combines them with data from Google Maps and Google Street View (for landmarks, traffic signs and lights). Another example is automated or algorithmic trading systems (ATS), where stocks are bought and resold within fractions of a second. In the United States, algorithmic trading is estimated to account for more than half of all trades (Figure 5.5).

Figure 5.5. **Algorithmic trading as a share of total trading**



Note: 2013-14 based on estimates.

Source: OECD calculations based on *The Economist* (2012), “High-frequency trading: The fast and the furious”, *www.economist.com/node/21547988*, and Aite Group (2012), *The Next Generation of Execution Consulting Services: Leveraging Technology to Build Relationships*.

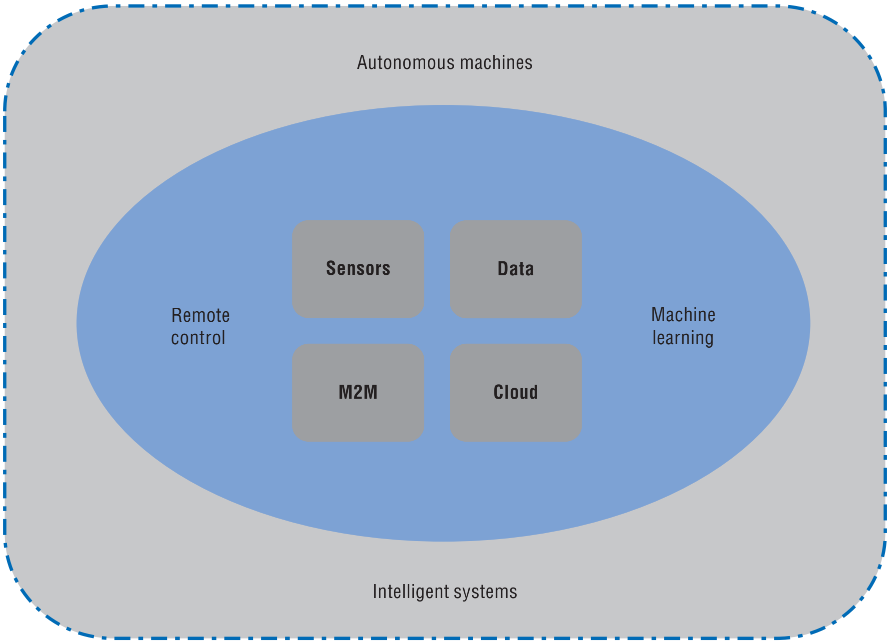
5.7. The Internet of Things

In 2012, the OECD estimated that an average family with two teenagers had ten Internet-connected devices at home (OECD, 2013b). By 2022 there could be as many as 50 devices per home, totalling 14 billion such devices across the OECD. Estimates by Ericsson, Cisco and Intel show that the number of Internet-connected devices might grow to 50 billion over the next two decades. This phenomenon is known as the Internet of Things (IoT).

The IoT is also being linked to other advances in ICT, particularly in the areas of big data, the cloud, machine-to-machine (M2M) communication, and advanced sensors and actuators. The combination of cloud computing and big data analytics leads to improved machine learning applications. The combination of remote-controlled machines and systems with machine learning will lead to increasingly autonomous machines and systems (Figure 5.6). The economic benefits of the IoT could take the form of consumer surplus, new revenues and higher GDP growth as technologies are commercialised as well as increased firm productivity (for instance through new process optimisation and preventive maintenance strategies) (McKinsey & Company, 2013).

The development of autonomous machines is a goal of many innovations in ICT. Some examples of current developments include London's traffic lights, which operate with machine learning algorithms; the NEST learning thermostat; self-driving cars; and fully automated self-organising warehouses. Some services on smartphones, such as Google Now and Apple's Siri, demonstrate the possibilities of machine learning and autonomous systems (for example when they notify the user that it is time to leave for an appointment based on current traffic conditions). Such systems will increase in sophistication and their impacts will be felt across increasingly wide areas of the economy.

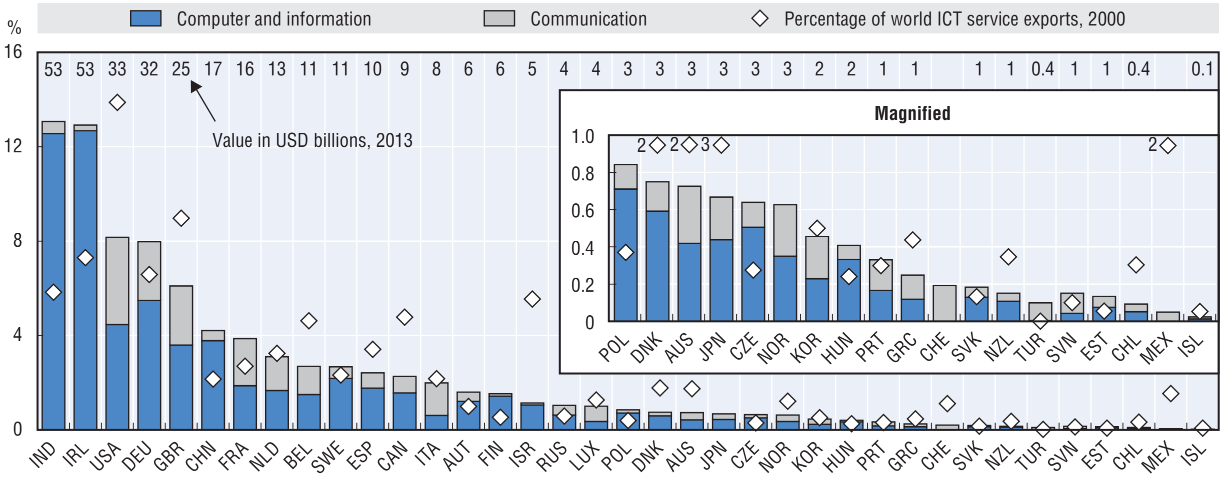
Figure 5.6. **Main elements of the Internet of Things**



5.8. The need for an open Internet

An open and accessible Internet with high fixed and mobile bandwidth is essential. The Internet's permission-free innovation, end-to-end connectivity and lack of gatekeepers gave companies such as Google, Skype, eBay, Hotmail and Alibaba an environment where they could experiment and refine their ideas. The open Internet doesn't just enable the exchange of data, information and knowledge; it also fosters global competition by allowing users to choose between service providers. For example, Internet users can make choices as to their Internet service provider, their browser and many other criteria (Clark, 2012). Furthermore, an open Internet enables the formation and management of GVCs in which companies increasingly spread production and supply-chain systems internationally. In addition, the economies of many countries are heavily rooted in cross-border ICT-related services. Countries such as Canada, France, Germany, Ireland, Japan, the Netherlands, the United Kingdom and the United States, among others, are particularly important in terms of their share of hosted web services and data centres as well as exported ICT-related services (Figure 5.7).

Figure 5.7. **OECD and other major exporters of ICT services, 2000 and 2013**



Source: OECD (2014f), *Measuring the Digital Economy*, *http://dx.doi.org/10.1787/888933148882*, based on UNCTADstat, *http://unctad.org/en/Pages/Statistics.aspx*, June 2013.

Barriers to the open Internet are likely to create significant economic costs. Some of the barriers to the free flow of data are the intended or unintended results of measures that affect the openness of the Internet. These barriers include technical measures (some of which aim to optimise the flow of data for specific purposes) such as Internet Protocol packet filtering, or "data localisation" requirements, whether through territorial restriction of Internet traffic or legal obligations to locate servers in local markets. Others aim to protect public values through the regulation of privacy and security, but as a result may also affect the openness of the Internet. The social and economic effects of limiting the openness of the internet are still unknown, and a comprehensive analysis is needed.

Many countries wish to find consensus on how to maintain a vibrant and open Internet. The OECD's High-Level Meeting on the Internet Economy, on 28-29 June 2011, discussed the openness of the Internet and how best to ensure continued growth and innovation in the Internet economy. The resulting draft communiqué led to the *OECD Council Recommendation* *on Principles for Internet Policy Making* (2011b). That communiqué contains basic principles for Internet policy making which, if followed, would help ensure that the Internet remains an open and dynamic platform for innovation and growth. Some of the key policy messages related to ICT, big data and the Internet are included below.

Main policy messages: ICT, big data and the Internet of Things

While a focus of important innovations, the use of data and data analytics brings major economic and societal challenges that governments need to address. These include enabling data-driven innovation by:

- Stimulating investments in broadband, smart infrastructure and the IoT as well as in data and analytics with a strong focus on SMEs and high value-added services (i.e. data analytic and data-driven services). This also includes investment in R&D.
- Fostering data-driven innovation in the public sector, including healthcare, science and education. However, domain-specific policy issues deserve consideration as there may be significant differences in the policy issues faced in these different fields of policy.
- As described elsewhere in this report, framework conditions for business must encourage organisational change and entrepreneurship in the private and public sectors.
- Promoting skills and competences in data analytics. Data specialists account for around 0.5% of total employment in most OECD countries. A lack of skills is a frequent barrier to the adoption of data-driven innovation. Also needed are domain-specific competencies to make informed data-based decisions, and to identify opportunities for data-based innovations.
- Removing unnecessary barriers to the development of the IoT. Because the IoT will affect so many aspects of society, many rules and regulations will need to be revisited. Rules regarding telecommunications networks and services (numbering), e-health (certification, compensation for doctors), transportation (self-driving vehicles, remote-controlled aircraft, regulations on taxi services), construction (building codes, energy savings) and many others may need to be updated.

Governments also need to work with other stakeholders to preserve the open Internet, and take measures to understand the economic and social costs of barriers to an open Internet. Governments therefore need to address the following challenges:

- **Preserving the open Internet and promoting the free flow of data across the global data ecosystem so as to facilitate data-driven innovation.** This includes encouraging data sharing and promoting open access to data, as well as the interoperability of data-driven services, through open standards and application programming interfaces. It also includes promoting data portability across applications.
- **Encouraging multi-stakeholder co-operation.** Multi-stakeholder processes have been shown to provide the flexibility and global scalability required to address Internet policy challenges.
- **Addressing individuals' concerns about harms caused by privacy violations.** Data-driven innovation can infringe core societal values around autonomy, equality and free speech. Key means of addressing such concerns include enhancing the transparency of data processing, promoting the responsible use of personal data and the effectiveness of privacy enforcement, and encouraging privacy risk management. The most difficult policy challenge is the operational and legal definition of the boundaries determining when responsible data use must apply and when decision automation is permissible.

Main policy messages: ICT, big data and the Internet of Things *(cont.)*

- **Addressing concerns related to the appropriation of returns on investments in data-driven innovation.** IPRs may need to be recalibrated to enable sharing of data in some cases, particularly because data ownership remains a challenging concept. Alternative incentive mechanisms including a copyright regime such as Creative Commons, and open source software licences, in combination with mandatory data citations in publications, should be considered further.
- **Assessing market concentration and barriers to competition.** Data-driven innovation may challenge traditional approaches to ensuring competition. How to define the relevant market and assessing the degree of market power and potential consumer detriments due to privacy violation deserve further consideration. Achieving policy coherence will also require promoting a dialogue among regulatory authorities, in particular competition, privacy and consumer protection authorities, so that: 1) potential consumer detriments due to data-driven innovation are taken into account; 2) synergies in the enforcement of rules controlling privacy violations, anti-competitive practices and mergers are realised; and 3) firms are incentivised to compete on and invest in privacy-enhancing goods and services as well as privacy-enhanced goods and services.
- **Improving measurement to prevent erosion of the tax base.** The global data ecosystem challenges the ability of tax authorities to determine the location of tax-relevant economic activities. Improved measurement will help in assessing the economic value of data assets and identifying where such activities occur.
- **Promoting a culture of digital risk management across society.** The openness and interconnectedness of the data ecosystem challenge the applicability of a traditional approach to digital security, which favours a closed digital environment. A modern risk-based approach to digital security is needed.

5.9. Intellectual property rights and innovation

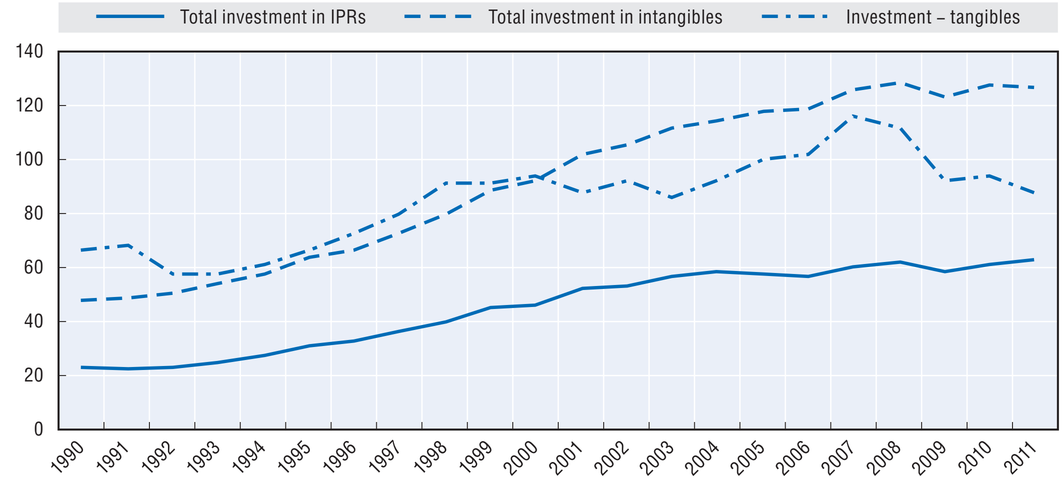
Why is IP important for innovation? The economic rationale for IP rights is that it is in everyone's long-term interest for people and businesses that create knowledge to have well-defined, enforceable rights to exclude third parties from appropriating their inventions and creative works, or the expression of such works, without permission. Failing to put restrictions on appropriating others' inventions and creations dilutes the rewards to investment in innovation, thereby reducing the incentives for making such investments.

IP is pervasive today. Until recently, IP policy mainly affected just a few specific sectors such as pharmaceuticals and artistic content. IP's influence is now economy-wide, affecting a wide swathe of sectors and demand. Today, a mobile phone may have as many as 3 000 different patents. The development of technologies such as digitisation and the Internet has brought consumers into more direct and frequent contact with copyright laws by making it easier, faster and cheaper to create, duplicate and disseminate content. Consequently, IPRs have become a mainstream framework condition that has a broad effect on innovation.

In the past, firms that used IP tended to rely more frequently on one particular type, and to the extent that they owned multiple kinds of IP, these may have been used in very distinct parts of the firm's business operations. For example, media companies could rely almost exclusively on copyright while maintaining trademarks on their brand names. Today, more companies use a bundle of IP rights. For instance, in-house software used in product design and manufacturing is common at larger firms and is typically protected by copyright, while the products themselves may be protected by patents, trademarks and, again, copyrights. Indeed, evidence suggests that firms worldwide increasingly rely on the joint use of patents, trademarks and industrial designs.

Looking at evidence on IP's aggregate economic role, three main points emerge: IP's economic importance has grown over time, investment in IP-protected assets was resilient during the economic crisis, and that investment is growing much faster than investment in physical assets (see also OECD, 2014a). Figure 5.8, for example, illustrates all three points:

Figure 5.8. **Total UK investment in tangible and intangible assets, including intellectual property, 1990-2011**



Source: Derived from data in Goodridge, Haskel and Wallis (2014), "Estimating UK investment in intangible assets and intellectual property rights", and from supplementary data provided by Professor Goodridge.

Copyright and trade secrets have a bigger role than some might have thought. Indeed they may in some respects be the most economically significant forms of IP. Investment in copyrighted works in the United Kingdom has grown more than investment in any other form of IP-protected asset (with the possible exception of trade secrets), more than tripling on a nominal basis between 1990 and 2011. As of 2011, by far the largest component of IP-protected investment in the United Kingdom involved copyrighted works, which drew more than twice the amounts invested in unregistered designs and trademarks, and nearly five times the amount invested in patents (Goodridge, Haskel and Wallis, 2014). Furthermore, copyright has also had a relatively strong impact on jobs in the United States in comparison with the impact of other forms of IP. Employment data show that job growth in copyright-intensive industries far outpaced that in trademark- and patent-intensive industries from 1990 to 2011. In fact, during that period, employment actually contracted in the latter category of industries, and markedly so in the patent-intensive group (US Department of Commerce, 2012).

Yet the economics of copyright and trade secrets has been less researched, mainly because data are less readily available.[8] While it is difficult to obtain data on trade secrets due to their nature, more could be done to improve data availability with respect to copyright. For example, governments could fund research and surveys to estimate the benefits of copyright registration. Then they could encourage voluntary copyright registration by enhancing the protections available for registered copyrights. They could also change the accounting rules that apply to creative industries to enable better data collection.

IP frameworks and stakeholders have been and continue to be affected by a number of broad developments, including the rise of cloud computing, the growth of the Internet, digitisation and globalisation. These developments have created new challenges for IP, for instance by facilitating piracy and industrial espionage. But they have also created new opportunities for IP to stimulate and diffuse invention and creativity. For example, new business models and research tools (based for instance on text and data mining, open access and e-content) hold the promise of stimulating diffusion.

New OECD indicators, including several composite indices, have been tested with data from the European Patent Office. The composite indices are consistent in that they show: 1) The average technological and economic value of inventions protected by patents has eroded over time, at least up to and including 2004, possibly reflecting application backlogs and strategic behaviour such as defensive patent filings; 2) patented micro- and nanotechnologies have the highest economic and technological value; and 3) Australia, Canada, Norway, South Africa, and the United Kingdom are the countries with the highest average economic and technological patent values (Squicciarini, Dernis and Criscuolo, 2013).

To provide a way to study the relationship between the strength of trade secret protection in an economy and that economy's performance, the OECD recently developed an indicator of the stringency of protection of trade secrets. With a broad sample of 37 OECD and non-OECD countries and data from 1985-2010, the indicator has been used to test the hypothesis that more stringent protection of trade secrets is associated with greater innovation and diffusion. The results show a positive and statistically significant relationship between the stringency of trade secret protection and indicators of innovation inputs (Lippoldt and Schultz, 2014). While these results do not mean that ever-stronger protection will yield similar results, the positive and statistically significant relationships identified do indicate that adequately protecting trade secrets may be an appropriate policy for supporting certain key aspects of economic performance.

While experiencing growth in terms of the number of industrial designs contained in applications, some studies suggest that design rights do not seem to be terribly important to innovation. While, according to one study, design is significant for 85% of businesses in the United Kingdom, a mere 4% of these businesses use registered designs (and only another 4% use unregistered designs). Nevertheless, earlier work indicated that shares of companies that were "effective users of design" (but not necessarily design rights) outperformed the stock market in the United Kingdom by 200% between 1994 and 2004 (Design Council, 2005). That raises questions about the effectiveness of design rights for motivating investment in design; further empirical work is clearly needed in this area.

The patent arrangement – granting exclusive rights in exchange for more inventions and better dissemination – could be more fully achieved if certain steps are taken to improve both the disclosure and the diffusion of information. Some surveys suggest that the information contained in patents is not in fact very useful to disclose information on the innovation. Opinions tend to vary by sector, though, with respondents in biotech, medical devices and computer hardware having relatively favourable views and those in the software and nanotech sectors being less favourable. Views also vary by firm size, with SMEs being four times less likely to consider patent disclosures important than large manufacturing firms. Experts at a recent OECD workshop suggested several ideas for improving the effectiveness of disclosure requirements, including more enforcement, ensuring that patent information is more up to date by reducing the time between filing and publication, and continuing to improve access by moving patent databases online and making them freely available.

IP can facilitate business finance, especially for SMEs, in two ways. First, IP can serve as a signal of a firm's quality (both managerial and technological), which helps to compensate for information asymmetries. Second, IP can boost profitability because it confers exclusive rights to use inventions or creations, which can lead to competitive advantages. If there is a well-functioning secondary market for IP, the IP can also be sold if the firm that owns it has trouble repaying its loans. In other words, IP can serve as collateral in debt financing. Indeed, a substantial body of empirical work has found that young, high-growth firms with IP assets receive more funding than firms without IP. Nevertheless, IP-based finance is significantly underused, especially by SMEs, which are most in need of it. One reason for this is a lack of opportunities to sell IP in secondary markets. Policy makers in several countries are striving to support IP markets. Generally, their efforts fall into two categories: 1) supporting greater transparency of IP ownership and transfer information via disclosure requirements or measures to foster greater clarity in patent claims; for example, to enhance clarity in patent claims, the US Patent and Trademark Office (USPTO) has strengthened the technical training of patent examiners and made it easier for external experts to contribute to that training; and 2) creating new IP market infrastructures. Another approach that governments can take is to help manage the risks associated with collateralising IP. Government agencies and development banks can do that through risk-sharing mechanisms. Some key findings from the OECD's work on IPR and innovation are included below.

Main policy messages from the OECD's work on IPR and innovation

- IP's overall role in economies has evolved from a niche policy area that was relevant to only a handful of industries to a force that influences a wide swathe of demand and sectors. Consequently, IP policy has become a mainstream framework condition that has a broad effect on innovation, among other areas such as trade, competition, taxes and consumer protection.
- Copyright appears to be the type of IP with the most impressive economic performance, and it is undergoing more statutory change than other IP types, yet there are fewer empirical studies about copyright than about patents. Encouraging and enabling the collection and availability of more data on copyright would facilitate data-driven copyright policy.
- SMEs are better at creating jobs than large companies, but it has become harder for SMEs to find financing. Making it easier to use IP as a basis for obtaining financing would help SMEs to drive job growth and spur innovation.
- To lever the economic benefits of patents, steps should be taken to improve the diffusion of patent information.
- Recent, exploratory OECD work on trade secrets suggests a link between trade secret protection and innovation. Further work in this area would be worthwhile.

5.10. Knowledge networks and markets

The OECD introduced the concept of knowledge networks and markets (KNMs) in the 2010 Innovation Strategy (OECD, 2010a). KNMs are the set of systems, institutions, social relations, networks and infrastructures that enable the exchange of knowledge and associated IPRs. The term “KNM” has grown in popularity and has been applied to a very diverse set of agreements, institutions, organisations and intermediaries in the innovation system. Broad categories of KNMs can be defined on the basis of whether their focus is on:

- facilitating the transfer of disembodied knowledge, as in the case of searchable registers and repositories of existing data and information
- providing platforms for sourcing solutions to *ad hoc* problems and challenges (including platforms for innovation prizes or identifying consultants to assist with new R&D projects)
- resolving ownership of, and the transfer of rights to, disembodied knowledge (IP brokers, patent pools and funds primarily deal with the allocation of IP rights and the management of financial assets and liabilities attached to these rights)
- the transfer of knowledge embodied in people
- transforming the nature of the knowledge embodied in goods or people (for example, standard-setting organisations codify existing know-how and best practices embodied in a community of practice).

KNMs are many and varied. (OECD [2013c] discusses schema for classifying KNMs.) This section briefly outlines developments and challenges associated with online knowledge marketplaces and KNMs in the field of synthetic biology.

Online knowledge marketplaces (OKMs) manage platforms that communicate, match and transact innovative knowledge (Dushnitsky and Klueter, 2010). In general, OKMs are independent entities, unaffiliated with either knowledge owners or seekers. Many operate as for-profit companies, but some are not-for-profit ventures that rely to different degrees on member subscriptions, fees or other support. OKMs share similarities with more widely known online marketplaces for goods and services, such as the ambition to exploit economies of scale and scope.

Dushnitsky and Klueter (2010) studied 30 prominent websites that act as marketplaces in which owners of knowledge (e.g. a patent owner or an entrepreneur with an innovative business idea) interact with knowledge seekers (e.g. potential licensees or prospective investors). They find that IP-related OKMs systematically require entrepreneurs and inventors to disclose their inventions and/or pay upfront fees as a prerequisite for participation. Both mechanisms appear to alleviate the problem of adverse selection (but their effectiveness as an inducement to widespread market participation may be limited).

While OKMs may attract owners of high-quality inventions, their anonymity and speed might result in domination by low-quality ideas. Anonymity has benefits, such as lower risks when information is disclosed, but it also helps to dilute the reputational ties that bind parties together and contribute to building trust. To be efficient, OKMs typically require standardised procedures to collect and convey information about the knowledge procured and the knowledge offered. Otherwise, they would not deliver services at a significantly lower cost than the sum of individual, uncoordinated search efforts. In this connection, emerging semantic technologies can be important for organising and communicating information about knowledge.

It is important for policy makers to consider how knowledge markets support the growth of promising new general-purpose technologies, drawing lessons from experience in other technology domains (OECD, 2012c). For example, the emerging field of synthetic biology relies heavily on engineering and computer science (OECD, 2014g). As noted by

Torrance and Kahl (2012), among others, disciplinary features of synthetic biotechnology require more consideration of standards setting, interoperability and interchangeability than is usual in other areas of biology. By operating at the intersection of biotechnology and information technology, synthetic biotechnology has the potential to be affected by IP problems that exist in both fields. For example, synthetic biologists have argued that strings of DNA bases are comparable to source code and that DNA strings could therefore be covered by copyright. However, Rai and Boyle (2007) have questioned the appropriateness of invoking copyright protection in this domain, owing for example to the wide scope for expressive choice when constructing DNA sequences with base pairs that do not exist in nature.

Probably the best-known KNM in the field of synthetic biology is the BioBricks Foundation (BBF), which has created a registry and repository of standard biological parts (the building blocks of synthetic biology). Scientists can browse the BioBricks catalogue and contribute new parts that conform to the foundation's specifications. BioBricks has created a technical standard, an open technology platform and a repository open to anyone interested in building new biological parts.

Among the standards-setting groups that have formed in the synthetic biology community, most express a preference for standards that remain open and accessible to the community as a whole. In this early development stage, academics play an important role, and the public ethos is quite visible. Synthetic biology also illustrates a potentially symbiotic relationship between open and proprietary innovation models. For example, the dissemination of synthetic biology "parts" on a free and open basis would likely increase demand for various proprietary DNA-synthesis platforms. Some of key policy messages related to knowledge networks and markets are included below.

Main policy messages: Knowledge networks and markets

Because KNMs are so diverse, only highly generic policy messages will have broad relevance. In this connection, key points are that:

- Promoting specific knowledge markets should not be considered as a policy objective in its own right. Rather, KNMs represent a set of potential instruments for achieving a wide range of policy goals.
- Policy should not continue to support networks once they are established and their benefits are clear to participants. At this stage, all participants should have found and put in place mechanisms for contributing fairly to costs, while sharing benefits. The government's role should shift to addressing problems that may be due to established networks (such as detrimental effects on competition in product markets).
- Improved measurement is needed. Through the OECD's work on KNM indicators, four broad areas for measuring knowledge flows have been identified: 1) **skills mobility and knowledge flows**. The knowledge embodied in people and the very different types of data required for tracing such flows warrant special measurement efforts; 2) **disclosing and accessing knowledge**. Analysing access to and the use of knowledge sources, including repositories of disclosed information on science and technology, is of key importance; 3) **transactions on knowledge and knowledge rights**. Traditional and new evidence sources should be used to shed light on how different actors transact with other parties to procure knowledge; and 4) **co-creating knowledge**. Beyond transactions, good indicators are needed of collaboration in the creation of knowledge.

Notes

1. Returns to investments in basic science vary across countries. This point, which has not been subject to extensive study, could have significant policy implications. For instance, it is relevant to the issue of whether small economies might benefit from pooling research resources, rather than employing those resources individually.
2. Forthcoming OECD work does point to an important contribution of investment in basic research to long-term productivity growth, however.
3. In the first half of the 2000s, two important and widely referenced university rankings were established: *The Academic Ranking of World Universities* (first published in 2003), known as the "Shanghai Ranking", and the *Times Higher Education World University Ranking* (first published in 2004). A host of similar rankings followed.
4. The NIH has made its public access policy mandatory: all funded researchers must submit an electronic version of their final peer-reviewed manuscripts to PublicMed Central.
5. A recent survey of European universities identified 59 proof-of-concept/seed funds, of which half are in the United Kingdom (19) and Belgium (11) (Toschi, 2013).
6. In 2007 the OECD defined the information economy as the aggregate of the ICT and digital media and content industries. This aggregate includes ISIC Rev. 4 Division 26 (manufacture of computer, electronic and optical products) and Section J (information and communication services) consisting of Divisions 58-60 (publishing and broadcasting industries), 61 (telecommunications) and 62-63 (computer programming and information services). ICT trade and repair activities (in Groups 465 and 951) are also included, but are not considered in this chapter due to data availability.
7. Furthermore, OECD data indicate that international co-operation increases the quality of research (OECD, 2013).
8. Some countries have undertaken special statistical surveys on the management of intellectual property, e.g. Canada's Survey of Intellectual Property Management: *www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5183&lang=en&db=imdb&adm=8&dis=2*.

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