OECD Science, Technology and Innovation Outlook 2016

Chapter 3

The future of science systems

This chapter focuses on public research systems and the potential shifts that they are likely to experience over the next 10-15 years. While public research systems have their own specific trend dynamics – for example, with regard to research funding, where and how research is performed and reported, and researcher career paths – they are also affected by wider changes in economies and societies. This chapter explores what these changes might mean for public sector research, raising eight main questions about its future: What resources will be dedicated to public research? Who will fund public research? What public research will be performed and for what purpose? Who will perform public research? How will public research be performed? What will public research careers look like? What outputs and impacts will be expected of public research? And what will public research policy and governance look like?

Introduction

Public research plays a key role in innovation systems, providing new knowledge and know-how that can enhance the development of new technologies for societal or economic purposes and that businesses are not always well equipped or incentivised to invest in (see the policy profile “Public research missions and orientation”). Many of today’s innovations would not have been possible without the scientific and technological developments enabled by public research. Well-known contemporary examples include recombinant DNA technologies, the GPS global positioning system, MP3 technology for data storage, and voice recognition technology such as Apple’s Siri.

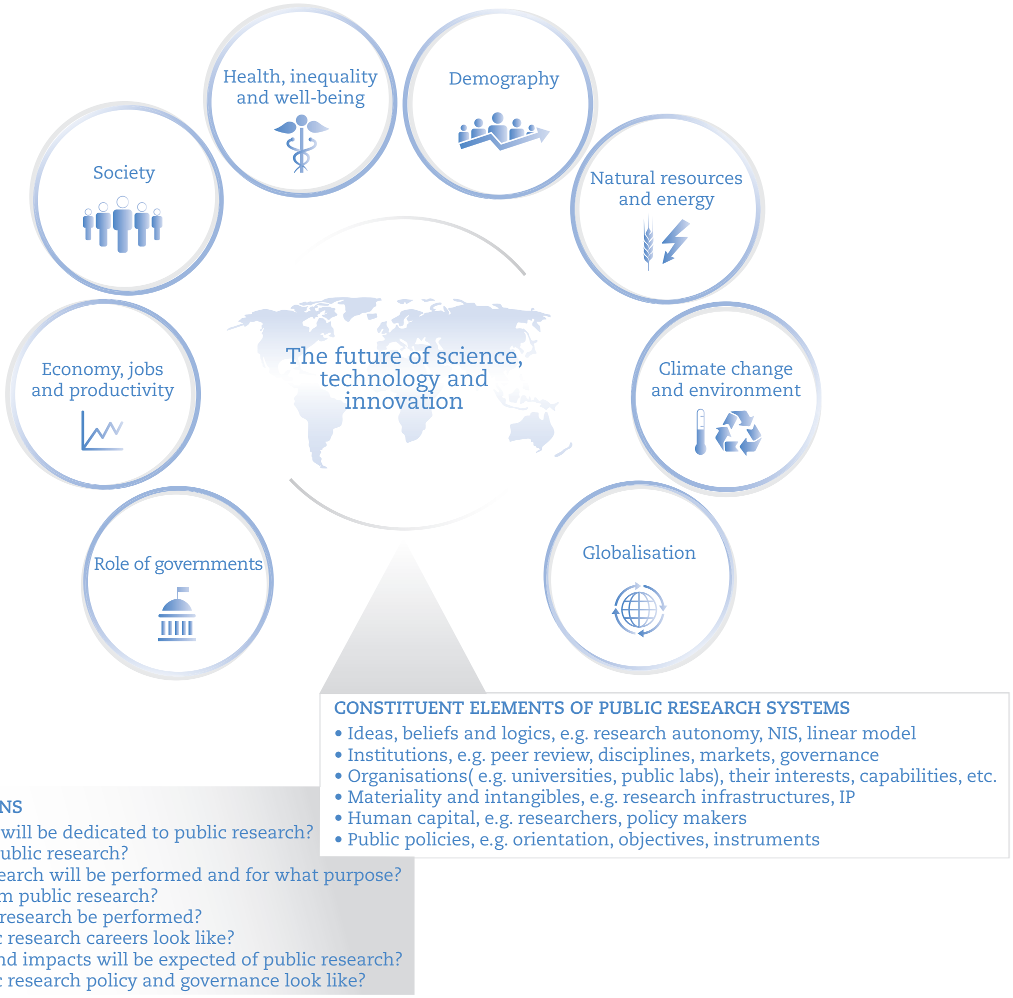
Universities and public research institutes (PRIs) often undertake longer-term and higher-risk research. Although they account for less than 30% of total OECD research and development (R&D) expenditure, universities and PRIs perform more than three-quarters of total basic research. They also undertake a considerable amount of applied research and experimental development that has more immediate potential for translation into tangible societal benefits. As the main funders and shapers of public research, governments have the potential to influence global and national science systems, well beyond the administrative and institutional borders of the public sector.

Public research systems are shaped by many of the megatrends and technology trends discussed in the previous chapters. For example, environmental and health challenges will substantially shape future research agendas, while technological change, particularly growing digitalisation, will affect the way research is performed. At the same time, public research systems have their own specific trend dynamics, for example, with regard to research funding, where and how research is performed and reported, and researcher career paths. While these research-specific trends are clearly influenced by wider megatrends and technology trends, their dynamics are also shaped by long-standing institutional and organisational arrangements that characterise public research systems. They are also shaped by historically accumulated resources, including tangible and intangible assets and human capital. Taken together, these arrangements and accumulated resources provide a lens through which public research trend dynamics can be viewed.

Some of the issues covered in the chapter are still emerging, but most are long-established trends that may change quantitatively and/or qualitatively over the next 10-15 years. These include the ongoing expansion of public research across the world; the broadening variety of public and private funders of public research; and growing digitalisation and internationalisation of research, which are set to make science more open and raise expectations about the contributions of public research to economies and societies. All these issues are highly interconnected: sometimes trends are mutually reinforcing, but often they are in tension, leading to conflict and controversy and opening up the possibility for trend breaks and disruptions. This creates uncertainty about the future of many aspects of public research systems.

This chapter provides a high-level overview of the main trends and issues that are likely to shape public research systems over the next 10-15 years. It builds on some basic trend analysis carried out in the *STI Outlook 2014* (OECD, 2014a), and extrapolates this further into the future, drawing in part on the megatrends set out in Chapter 1 and the technology trends presented in Chapter 2. It is based on desk research, a series of internal and external expert workshops as well as interviews with international experts and academics on the future of science systems. The chapter is structured around eight main questions concerning public research resources and funders, research performance and impacts, research careers, and research policy and governance, as shown in Figure 3.1.

Figure 3.1. **Outline and main issues of Chapter 3**



CONSTITUENT ELEMENTS OF PUBLIC RESEARCH SYSTEMS
- Ideas, beliefs and logics, e.g. research autonomy, NIS, linear model
- Institutions, e.g. peer review, disciplines, markets, governance
- Organisations(e.g. universities, public labs), their interests, capabilities, etc.
- Materiality and intangibles, e.g. research infrastructures, IP
- Human capital, e.g. researchers, policy makers
- Public policies, e.g. orientation, objectives, instruments

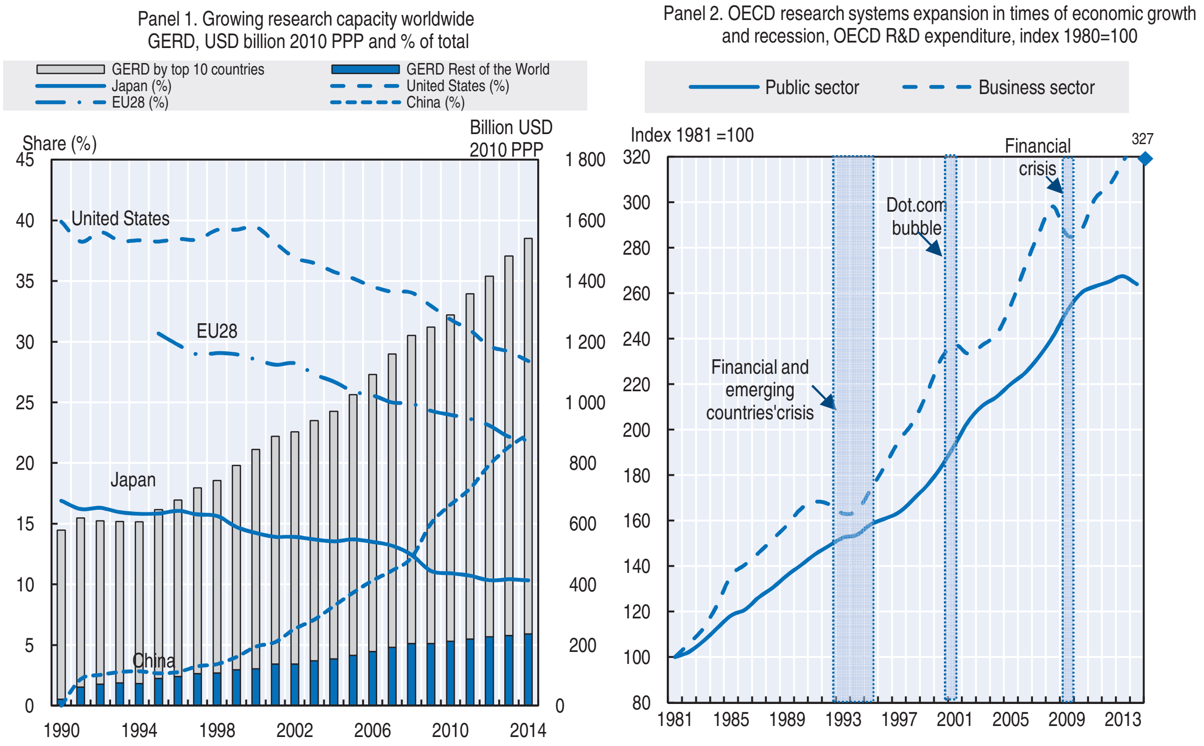
EIGHT MAIN QUESTIONS
3.1. What resources will be dedicated to public research?
3.2. Who will fund public research?
3.3. What public research will be performed and for what purpose?
3.4. Who will perform public research?
3.5. How will public research be performed?
3.6. What will public research careers look like?
3.7. What outputs and impacts will be expected of public research?
3.8. What will public research policy and governance look like?

3.1. What resources will be dedicated to public research?

Global R&D capacity has doubled in the last 15 years[1] (Figure 3.2, Panel 1), a remarkable expansion driven by two important factors. First, business expenditure accounts for a growing share of global R&D as firms' expenditure on R&D has increased faster than public R&D expenditure during times of economic growth (Figure 3.2, Panel 2). Although firms will continue to rely on intangible investment and innovation to compete in global markets, the expansion of business R&D expenditure may slow or even halt. Weak recent economic performance, coupled with investment strategies that favour short-term shareholder value, may diminish firms' ability and willingness to undertake risky projects and to invest in research activities (see Chapter 4).There has actually been a slowdown in business investment in intangible assets in many OECD countries that could, in the longer run, disrupt knowledge accumulation and jeopardise the future capacity of firms to innovate.

Figure 3.2. **Business and public investment have expanded global research capacity**

Long-term shifts in gross domestic R&D expenditure (GERD)



Panel 1. Growing research capacity worldwide
GERD, USD billion 2010 PPP and % of total

Panel 2. OECD research systems expansion in times of economic growth and recession, OECD R&D expenditure, index 1980=100

Sources: Based on OECD (2016a), *Main Science and Technology Indicators (MSTI) Database, www.oecd.org/sti/msti*; Eurostat (2016), *R&D Indicators Databases*, *http://ec.europa.eu/eurostat/web/science-technology-innovation/data/main-tables*; UIS (2016), S&T Indicators, *www.uis.unesco.org/Pages/default.aspx*. Data extracted from IPP.Stat (2016) on 22 July 2016, *www.innovationpolicyplatform.org/content/statistics-ipp*.

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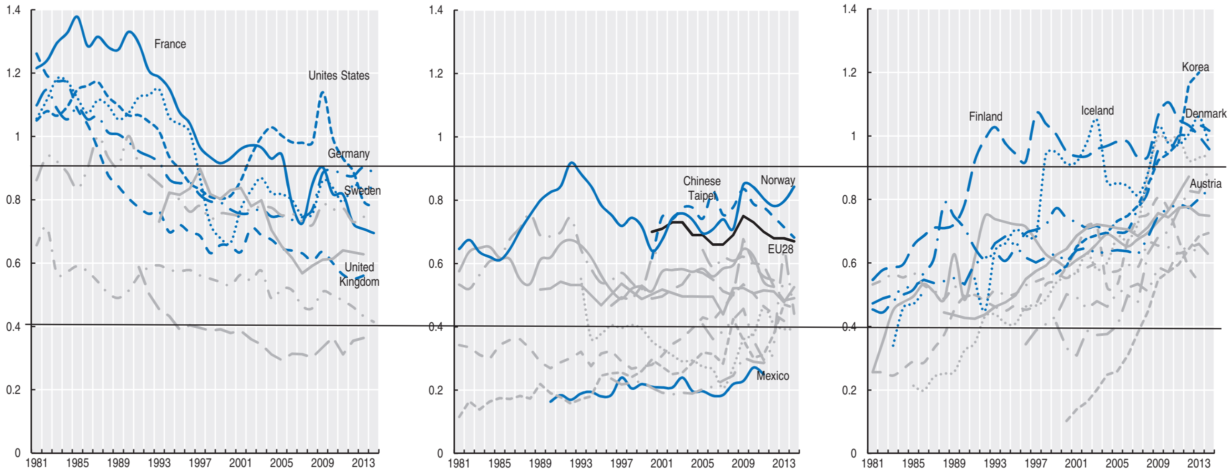
Second, several emerging economies, such as the People's Republic of China, have increased their R&D spending in past decades. OECD countries account for just a small portion of the increase in R&D capacity worldwide and their share of global gross expenditure on R&D (GERD) is in decline (Figure 3.2, Panel 1), a trend that is likely to continue given the growing weight of emerging economies in the world economy. At the same time, several emerging economies are showing signs of economic slowdown, which may reduce their capacity to increase R&D spending at the rates seen in recent years.

The challenges of ageing populations and slower economic growth will place considerable pressure on public spending in many OECD countries over the next 10-15 years: the competition for resources from other sectors, such as health and pensions, could even see declines in public investment in R&D. Indeed, the most recent data show the share of public R&D budgets in GDP declining in many OECD countries as governments pursue post-crisis austerity policies (Figure 3.3). On the other hand, R&D investment could be framed as a tool to keep increases in other public spending in check, e.g. by enabling more rapid innovation in areas like healthy ageing, which would have cost-savings.

Figure 3.3. **Public R&D budgets are likely to plateau around current ratios**

Government budget appropriations and outlays for R&D, as a % of GDP



Note: Panel 1 (decreasing budgets) includes Australia, France, Germany, Israel, the Netherlands, Poland, Sweden, the United Kingdom and the United States; Panel 2 (stable or slowly increasing budgets) includes Argentina, Canada, Greece, Hungary, Ireland, Italy, Mexico, Norway, New Zealand, the Slovak Republic, Slovenia, Chinese Taipei and the EU28; Panel 3 (fast increasing budgets) includes Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, Iceland, Japan, Korea, Luxembourg, Portugal and Spain.

Source: Based on OECD (2016b), *OECD R&D Statistics (RDS) Database*, April 2016, *www.oecd.org/sti/rds*.

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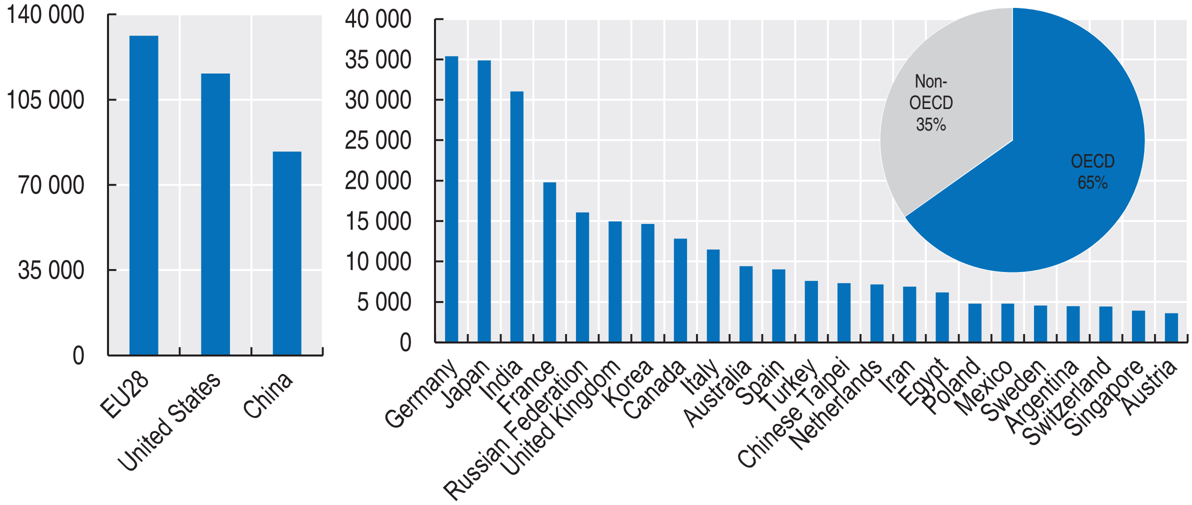
Long-term trends in government budget appropriations or outlays for research and development (GBAORD) show a convergence across countries in the intensity of public budgets allocated to R&D, measured as a percentage of GDP (Figure 3.3). Public R&D budgets oscillate between 0.40% and 0.90% of GDP which signals that public dedicated efforts to R&D may have reached their maximal intensity. The extremes include, at the bottom end, some lower-income Central European and Latin American countries, and at the top end, Korea, some Nordic countries (Denmark, Iceland and Finland) and Germany. Future increases in public R&D budgets might therefore be mainly driven by GDP growth, a growth that is expected to slow at a global level (see Chapter 1).

This points to the possibility of a more prominent role for emerging economies if they continue to enjoy high rates of economic growth in the future, which is far from certain. Already, scientific endeavour is no longer a preserve of high-income countries, with more than one-third of the world's public research concentrated in non-OECD economies (Figure 3.4). For example, China, with the second-largest science base in the world, spent around twice as much on public R&D as Japan in 2014. Similarly, India, the Russian Federation, Chinese Taipei, the Islamic Republic of Iran and Argentina maintain some of the largest public science systems in the world. A more multipolar global research landscape is therefore likely to emerge, with Asia in particular set to play an increasingly prominent role. Nevertheless, a few countries are likely to dominate: five economies (the United States, China, Japan, Germany and India) accounted for 59% of global public R&D in 2014, while 25 OECD countries and non-OECD economies accounted for 90% of the total. This dominance by a few in part reflects their large size. In the longer term, economies that are set to expand their populations and GDP markedly, for example, in Africa, could become more important global R&D players.

Figure 3.4. **Global public research is performed in a few OECD countries and partner economies**

Public R&D expenditure, USD million PPP, and world's share in %, 2014 or latest year available



Notes: Public R&D expenditure includes higher education R&D expenditure (HERD) and government R&D expenditure (GOVERD). The world total is estimated with countries for which data are available. Brazil is not included.

Source: Based on OECD (2016b), *OECD R&D Statistics (RDS) Database*, April, *www.oecd.org/sti/rds*. Data extracted from IPP.Stat (2016) on 26 July 2016, *www.innovationpolicyplatform.org/content/statistics-ipp*.

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3.2. Who will fund public research?

Any spending squeeze by national governments in OECD countries will pose many challenges for public research, since governments account on average for 90% of total higher education and government R&D expenditure (Figure 3.5). The dominance of government spending in public research is particularly striking in the largest public R&D performers, Japan (98%) and the United States (96%), which tends to skew the OECD average upwards. A similar situation exists in some emerging economies, for example, in Argentina (99%), Mexico (98%) and Chile (95%). Public research is slightly less dependent on funding from national governments in the European Union (83%), reflecting lower shares in the Netherlands (72%), Belgium (71%) and the United Kingdom (70%). In European countries, funding from the European Commission, which is also public funding, is important as well. This is particularly true for the southern and eastern European countries, which receive substantial support for R&D through the EU Structural and Cohesion Funds as part of EU regional policy to reduce intra-European disparities in income, wealth and opportunities (EC/OECD, forthcoming).

Despite fiscal pressures, national governments will remain the main funders of public research in the foreseeable future, but businesses may increase their financial contribution, both reflecting shortfalls in government funding on the one hand, and industry's interest in accessing complementary knowledge and sharing risk on the other. Universities are more likely to capture business funding, following long-term patterns in industry funding of universities and public labs' research (Figure 3.6). Public-private partnerships will remain strategic policy instruments and will help mobilise new sources of funding. Benefits include more immediate socio-economic impacts and increased flow of personnel and ideas between the two sectors. While increased business involvement may reinforce a desirable market perspective in academic research, it can also lead to growing short-termism and greater focus on incremental rather than fundamental, breakthrough research (see the policy profile “Strategic public-private partnerships in science, technology and innovation”). It may also affect other practices, e.g. in placing some restrictions on open data sharing (see below).

Figure 3.5. **Public research funding is concentrated in governments’ hands**

Public R&D expenditure, major funders, share in total, 2014 or latest year available

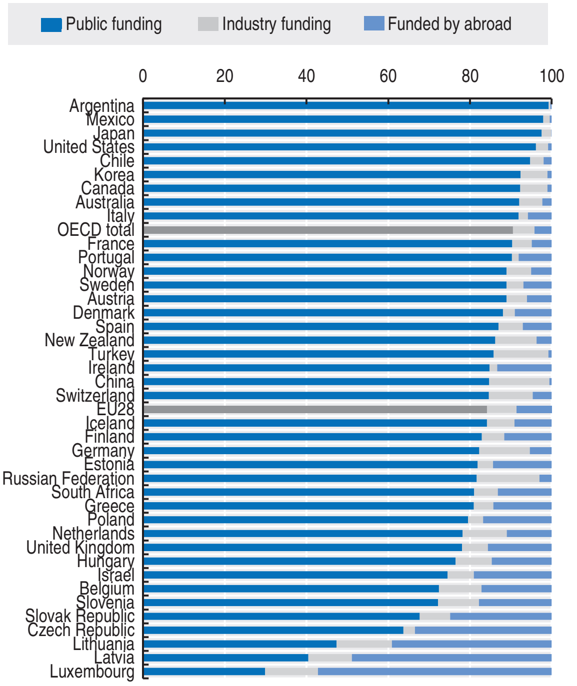

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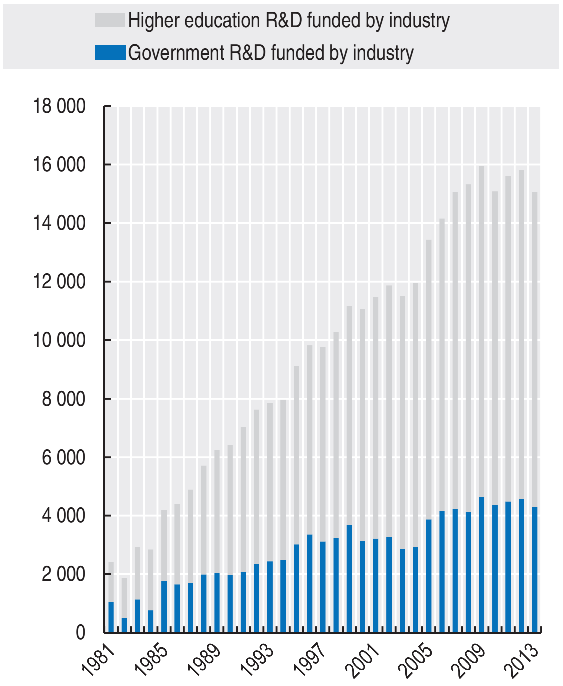
Figure 3.6. **Industry funding of public research: universities take the lion’s share**

Shift in R&D funding, OECD, USD million PPP at constant prices



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Notes: Public R&D expenditure includes higher education R&D expenditure (HERD) and government R&D expenditure (GOVERD). The world total is estimated with countries for which data are available.

Source: Based on OECD (2016b), *OECD R&D Statistics (RDS) Database*, April, *www.oecd.org/sti/rds*; Data extracted from IPP.Stat on 25 July 2016, *www.innovationpolicyplatform.org/content/statistics-ipp*.

Charities, foundations and philanthropists have become increasingly prominent funders of university research in recent years, a trend that may well continue. Such funding is especially prominent in the health domain – for example, the Wellcome Trust, based in the United Kingdom, funds a wide range of medical research, the French Association for Myopathy (Association française contre la myopathie) funds research on rare diseases, and the Gates Foundation provides a large share of global research funding related to tropical diseases (see the policy profile “Public research missions and orientation”).

While hardly a new phenomenon, science philanthropy – involving often large donations from wealthy individuals – is a fast-growing source of funding for public research (OECD, 2014a). Science philanthropy is typically concentrated in specific fundamental and translational research areas, as well as in institutions at the scientific frontier, and is estimated to provide almost 30% of annual research funds in leading US universities (Murray, 2012). This raises questions about the future of research for the public good: while private donations are widely welcomed, they can be oriented by personal interests and may be dissociated from public goals, thus diverting research towards peripheral fields (Broad, 2014). But, on the other hand, philanthropy often acts as a catalyst for attracting other funders, including the public sector, to support large-scale projects and centres that might otherwise remain unfunded on account of their high costs.

3.3. What public research will be performed and why?

The various megatrends presented in Chapter 1 will heavily influence future research and innovation agendas. Many urgent challenges call for new technological breakthroughs and large-scale institutional and organisational changes that will in part depend on new research. Some examples include: achieving more sustainable growth; the needs of ageing societies; environmental pressures, notably climate change; the depletion of natural resources; threats to energy, water and food security; and, various health issues.

There has already been a general shift in research policy agendas towards environmental and societal challenges, and the "greening" of national research policies has been prominent in many OECD countries since the late 2000s (OECD, 2010; OECD, 2012a). Country responses to the latest science, technology and innovation (STI) policy survey show that achieving sustainable growth or addressing societal challenges are among the top STI policy priorities in a growing number of OECD countries and emerging economies (see Chapter 4). This reorientation is reflected in public budgets for R&D, which have shifted in past decades towards environmental and health-related objectives (though not for energy). National GBAORD has increased faster on environment- and health-related issues than on other civil purposes (Figure 3.7).

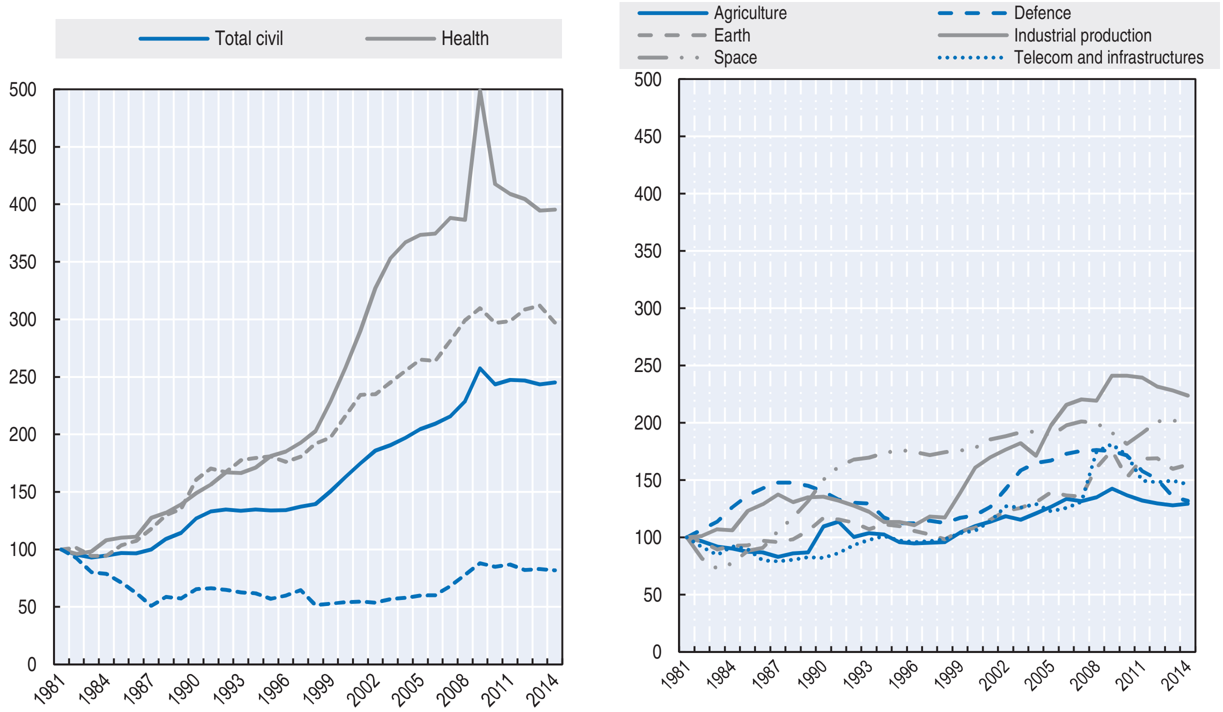
At the international level, the European Union's Horizon 2020 framework programme also focuses on a series of societal challenges, including health, demographic change, food security, sustainability, clean energy, green transport, climate action, and inclusive and secure societies, while the UN-initiated Sustainable Development Goals and the COP21 climate agenda both articulate roles for science and innovation in reaching their targets (see Box 3.1). However, many challenges are ill-structured "wicked problems", involve much uncertainty, and cannot be solved through science and technology alone. It will be important for future policy making to articulate the appropriate roles of science in the socio-technical transitions necessary to deal with these challenges and to adjust policy expectations accordingly.

The breakdown of public R&D budgets by socio-economic objective reveals certain specialisation patterns (Figure 3.8, Panel 1). For instance, the United States has a clear policy orientation towards health R&D (including medical science), which absorbs 24% of its public R&D allocation in 2016. The United Kingdom (22%), Luxembourg (18%), and Canada (17%), devote around a fifth of their R&D budgets to health issues.[2] Mexico (19%), Japan (11%) and Korea (9%) have prioritised energy R&D. While these specialisation patterns will certainly change over the next 15 years, significant shifts take time in the absence of major shocks, since sunk costs in research infrastructures and specialist research workforces imply a substantial degree of lock-in around current research fields.

The focus on societal challenges is unlikely to displace the long-standing emphasis on public science's expected contributions to national economic competitiveness. These concerns will still frame countries' research policy agendas, which will more than ever seek to better link public research with business needs and to attract and retain increasingly mobile knowledge assets, talent and S&T investments.

Figure 3.7. **Growing societal concerns are changing balances in public R&D budgets**

GBAORD, OECD, Index 1981 = 100, 1981-2014



Notes: R&D budgets for the control and care of the environment include research on controlling pollution and developing monitoring facilities to measure, eliminate and prevent pollution. Energy R&D budgets include R&D on the production, storage, transport, distribution and rational use of all forms of energy, but exclude prospecting and propulsion R&D. R&D budgets dedicated to health may underestimate total government funding of health-related R&D. Efforts to account for the funding of medical sciences via non-oriented research and general university funds help provide a more complete picture.

2009 Health data includes the one-time incremental R&D funding legislated in the American Recovery and Reinvestment Act of 2009.

Source: Based on OECD (2016b), *OECD R&D Statistics (RDS) Database*, April, *www.oecd.org/sti/rds*. Data extracted from IPP.Stat (2016) on 25 July 2016, *www.innovationpolicyplatform.org/content/statistics-ipp*.

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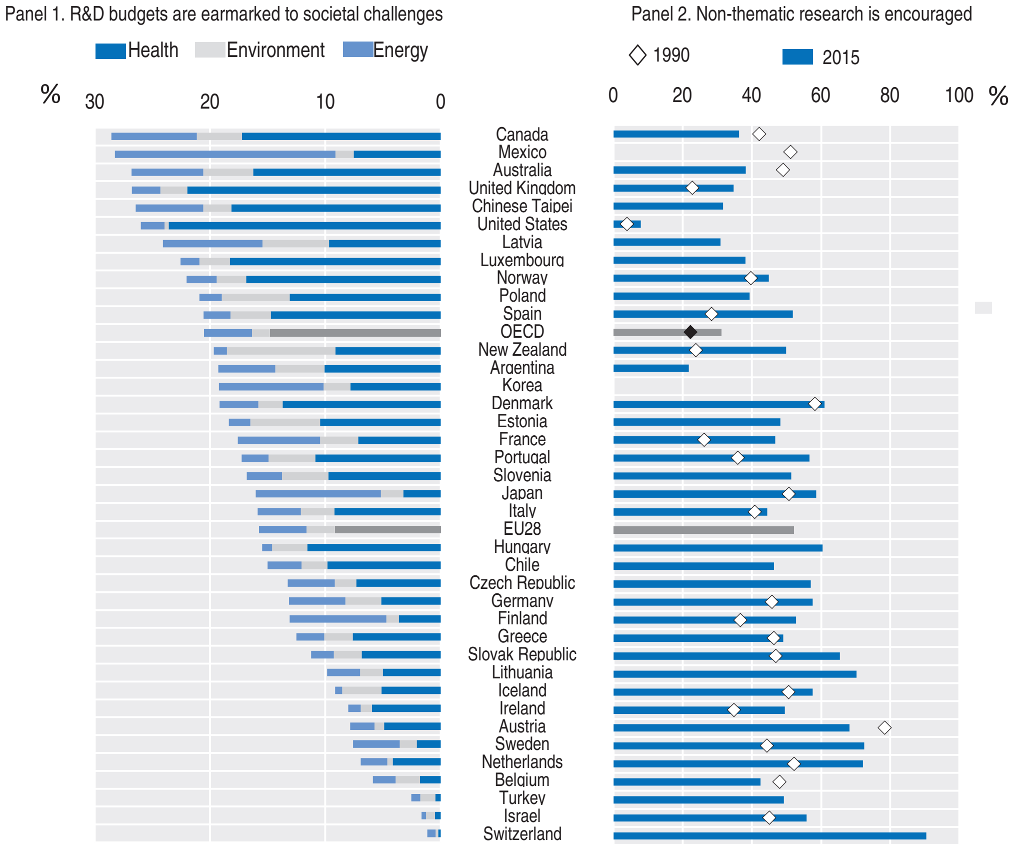
Box 3.1. **The Sustainable Development Goals and STI**

In September 2015, the United Nations adopted the 2030 Agenda for Sustainable Development, which identifies 17 Sustainable Development Goals, with a view to stimulating action over the next 15 years in all economic, social and environment areas of critical importance for sustainable development. The 2030 Agenda targets scientific research and calls for an increase in the number of R&D workers per 1 million people and a substantial increase in public and private R&D. It sets research priority areas in agriculture, health (e.g. vaccines and medicines for communicable and non-communicable diseases), clean energy (e.g. renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology) and marine health (e.g. ocean health and marine biodiversity).

Defence and security issues could also reassert themselves as priorities in national research agendas over the next 10-15 years if incidence of terrorism, risks of armed conflict – or perceived threats – rise. While militaries have for many years been among the biggest investors in scientific research, the proportion of government R&D expenditure devoted to defence in most OECD countries has fallen substantially since the end of the Cold War and is currently at historical lows. This could change if the international system becomes increasingly unstable, as some megatrends suggest (see Chapter 1). At the same time, the defence R&D budgets of emerging powers have grown markedly over the same period, and the People's Republic of China is believed to have the second-largest defence R&D budget in the world after the United States.

Figure 3.8. **Economies are setting R&D budgetary priorities to better address grand challenges**

Share in total GBAORD (%), 2016 or latest year available



Notes: In Panel 1, R&D budgets for the control and care of the environment include research on controlling pollution and developing monitoring facilities to measure, eliminate and prevent pollution. Energy R&D budgets include R&D on the production, storage, transport, distribution and rational use of all forms of energy, but exclude prospecting and propulsion R&D. R&D budgets dedicated to health may underestimate total government funding of health-related R&D. Efforts to account for the funding of medical sciences via non-oriented research and general university funds (GUFs) help provide a more complete picture.

In Panel 2, non-thematic research shares are proxies that include all GBAORD allocated for the general advancement of knowledge, including GUFs. Institutional grants (GUF) could however be distributed according to national research priorities set at national level. The United States is not included in the chart, since US data on GUFs are not available.

Source: Based on OECD (2016b), *OECD R&D Statistics (RDS) Database*, April, *www.oecd.org/sti/rds*. Data extracted from IPP.Stat on 25 July 2016, *www.innovationpolicyplatform.org/content/statistics-ipp*.

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Despite the emphasis on societal, economic and security challenges, the share of public R&D budgets allocated to non-thematic research (i.e. aimed at more general advancement of knowledge) will remain substantial. In 2015, such research accounted for more than two-thirds of the total public allocation in Austria, Austria, the Netherlands, Sweden, Lithuania, and Switzerland (2015 or latest data), and since the early 1990s this share has increased in most countries for which data are available (Figure 3.8, Panel 2). National US data also confirm an erosion of mission-oriented research (Sarewitz, 2012). Over the past 15 years, US mission-oriented agencies that seek principally to serve public goals rather than to advance science have experienced marginal budgetary growth, in some cases not even keeping up with inflation. During this same period, government funding for research almost doubled, and the National Institutes of Health (NIH)[3] and the National Science Foundation (NSF) captured three-quarters of increased federal spending for science.

The reasons for this shift in public research orientation are complicated and vary from country to country. Frequent important drivers include, however, a shift towards relatively autonomous universities as the main performers of public research and a strong policy emphasis on raising research excellence (as currently narrowly defined, i.e. essentially in terms of citations of articles published in leading journals). Broader notions of research excellence that place greater emphasis on the relevance of research for societal challenges could take hold over the next 15 years and could lead to more research spending being channelled along thematic, mission-oriented lines. It is also likely that universities will play enhanced roles in performing mission-oriented research, particularly as they form ever-closer relationships with PRIs and businesses (see below).

Developments in science and technology will also create new opportunities and challenges that will have a significant impact on research agendas over the coming decade. For instance, the potential of big data, neurotechnologies, artificial intelligence, and synthetic biology and their impact on research policies are discussed in more detail in Chapter 2. Making strategic choices on future priorities across very different fields will also be a challenge for research performers and funders alike. New research fields will emerge from the convergence of technologies (encompassing information and communication technologies [ICTs], nanotechnology, biotechnology and the cognitive sciences).

Many of the most significant breakthroughs in science and technology have come at the interfaces between disciplines. One example is synthetic biology where the overarching idea is to apply an engineering approach to biological systems, looking at such systems as living mechanical machines and building devices from standardised biological building blocks (Boyle and Silver, 2009). Synthetic biology applies principles, methods and practices from mathematics, engineering and computer science. It may have applications in manufacturing, the environment, agriculture and medicine (OECD, 2014b). Another example is neuroscience, where a variety of scientific disciplines overlap, from medicine, chemistry and genetics, to linguistics, cognitive science and psychology, to computer science, engineering and mathematics. Applications range from medicine itself (e.g. electronic implants that can repair or substitute brain functions), to brain-stimulation technology, to man-machine communication and interface technologies (e.g. neuro-prostheses).

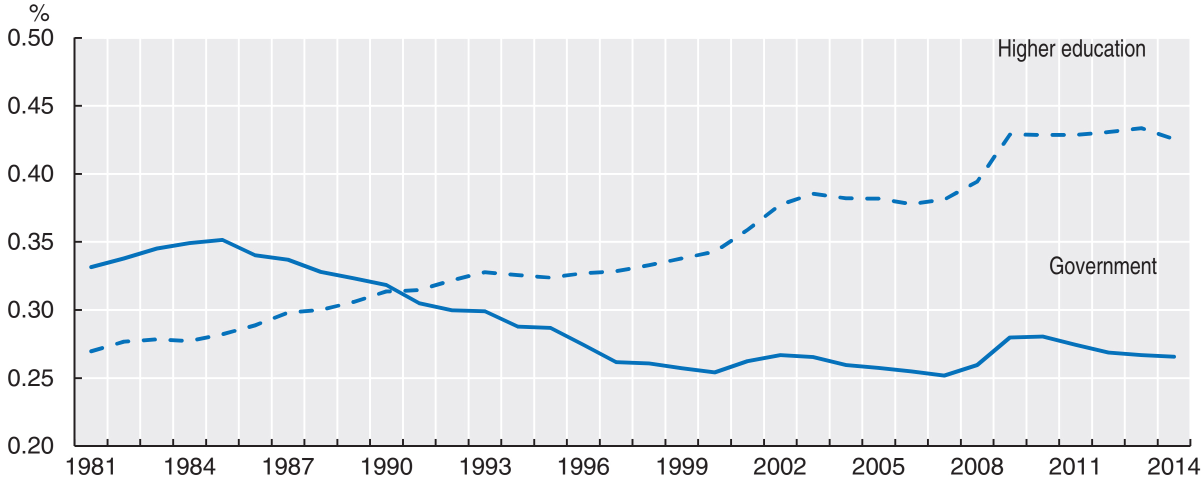
Complex global societal challenges inherently require research that combines traditionally distant academic fields, including the physical sciences and social sciences and humanities. Still, universities, peer review panels, funding agencies and scientific journals remain overwhelmingly organised along disciplinary lines that are not well set-up to accommodate cross-disciplinary activities. Research funders have paid increasing attention to breaking down disciplinary barriers in recent years, and this is set to continue, partially in response to the grand societal challenges but also in an effort to promote the development of disruptive technologies. In the future, this trend towards increasing inter-disciplinarity and trans-disciplinarity could be reflected both in the choice of strategic research priorities and in a re-structuring or bringing together of different research agencies and actors.

3.4. Who will perform public research?

There has been a global shift in national public research systems towards academic excellence and a concentration of resources in world-class research organisations, the vast majority of which are universities. The university model that links teaching and research more closely and involves students upstream in research activities has spread widely, and universities have taken the place of PRIs as the main performers of public research. The share of higher education expenditure on R&D (HERD) in total public research has increased steadily over recent decades in the OECD area, as the share of government expenditure on R&D (GOVERD) has declined (Figure 3.9). Still, universities and public research institutes are very heterogeneous. For example, in most countries, only a small percentage of universities carry out the majority of the research. Such universities often have a considerable degree of autonomy in how they balance and implement their missions, which is influenced by both their size and relative wealth, factors that vary enormously even within individual countries. So while such universities are a critical part of public research systems, governments typically have only limited direct control over them (see the policy profile "Public research missions and orientation").

Figure 3.9. **Public research has shifted towards universities**

R&D expenditure as a % of GDP, total OECD, 1981-2014



Sources: Based on OECD (2014a), *OECD Science, Technology and Industry Outlook 2014*, *http://dx.doi.org/10.1787/sti_outlook-2014-en*; OECD (2016a), *Main Science and Technology Indicators (MSTI) Database*, June, *www.oecd.org/sti/msti.htm*. Data extracted from IPP.Stat (2016) on 25 July 2016, *www.innovationpolicyplatform.org/content/statistics-ipp*.

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As for the public research institute sector, this typically includes a range of research performers, from those performing fundamental research using expensive large research infrastructures to others providing technical services to small and medium-sized enterprises. Those PRIs that focus on more applied research and that are closer to end-market needs have suffered particularly heavy funding cuts, and their existence in the public sector continues to be contested. A major challenge for such institutes has been their difficulty in accounting for the wide range of activities they perform, many of which are not readily amenable to audit and assessment using classical indicators. Many institutes also have large research infrastructures and ageing workforces that are expensive to maintain and that were developed for a different era when government and national industrial champions were major customers for their research. Over the next 15 years, as universities further ramp up their “third mission” and commercialisation activities and increasingly co-operate with the business sector, the overlap between the missions and tasks of PRIs and of universities is likely to grow, with the potential to increase both the competition and co-operation between them. In many OECD countries, public research institutes and universities are increasingly strongly linked through joint projects, PhD training, co-publication, joint appointments, joint research centres and, in some cases, co-location. A few countries, such as Denmark, have even taken the step of merging public research institutes with universities. Such linkages and mergers can be expected to grow in the face of further convergence in organisational missions and public spending constraints.

The move towards more open science (see below) and the advance of digital technologies could also promote citizen science initiatives and enhance public understanding of science (OECD, 2015a). The amount of R&D that is performed in non-public and non-business settings, i.e. by citizens and organised groups, while still quite small and marginal, is expected to increase markedly. Traditionally, such distributed activities are led by established scientists who use volunteer citizens to collect, organise and interpret data cheaply. For example, Galaxy Zoo uses volunteers to identify and classify vast numbers of astronomical images. The involvement of citizens in scientific efforts may also help to develop a culture of scientific awareness. Indeed, schools are increasingly considered an important target for the introduction and promotion of citizen science in some countries, and teachers are increasingly acknowledged for the role they play in facilitating the deployment of experiments and for transmitting socio-scientific values to the young audience.

More recently, “do-it-yourself science” has emerged, where citizens and organised groups conduct their own experiments and even maintain their own facilities or share publicly-accessible facilities. This remains a fringe activity at the moment but could grow significantly over the next decade. Do-it-yourself science could interface with public and private R&D in a variety of ways – as collaborators and user communities, but also as competitors and even opponents on some issues. Indeed, such activities fall outside the governance regimes of mainstream science, raising concerns over research quality and safety.

3.5. How will public research be performed?

Scientific research is itself highly dependent on technological developments and increasingly expensive research infrastructures. This situation has long been the case in physics, but now also applies to other research areas, including the social sciences and humanities. These outlays include large international infrastructures but also smaller-scale technology platforms, libraries and information archives, all of which need to be continuously updated and / or renewed. Large research infrastructures play a growing role in a range of scientific fields and allow many new discoveries. These facilities are dedicated not only to basic scientific research but also to providing direct scientific support for the resolution of major societal and environmental challenges. Strengthening public research infrastructures was among the top STI policy priorities in a majority of countries covered by the 2016 EC-OECD STI Policy questionnaire. For example, the United States is proposing a 10% increase in its 2016 budget for public research infrastructure, while Europe is expanding the number of jointly-funded European Research Infrastructure Consortia (see the policy profile “Financing public research”). Many large research infrastructure investments will also be made in East Asia over the next 15 years, reflecting the region’s growing research profile.

Taken together, large research infrastructure investments could herald a new era of "big science", driven by the scale of global challenges, increasing internationalisation, and evolving needs in scientific fields for more large-scale equipment and experiments. Such investments are politically attractive, but costly, and risk crowding out successful but less visible public R&D activities. Such potential trade-offs are particularly acute given future budgetary constraints. Governments will face difficult choices between funding "big science" or single investigator driven projects as well as between funding expensive research infrastructures or research personnel. Furthermore, a considerable and increasing proportion of scientific investment is going to developing and sustaining distributed infrastructures and e-infrastructures, including support for operating costs and skilled personnel, and this will be an increasingly important policy concern (see the policy profile "Financing public research").

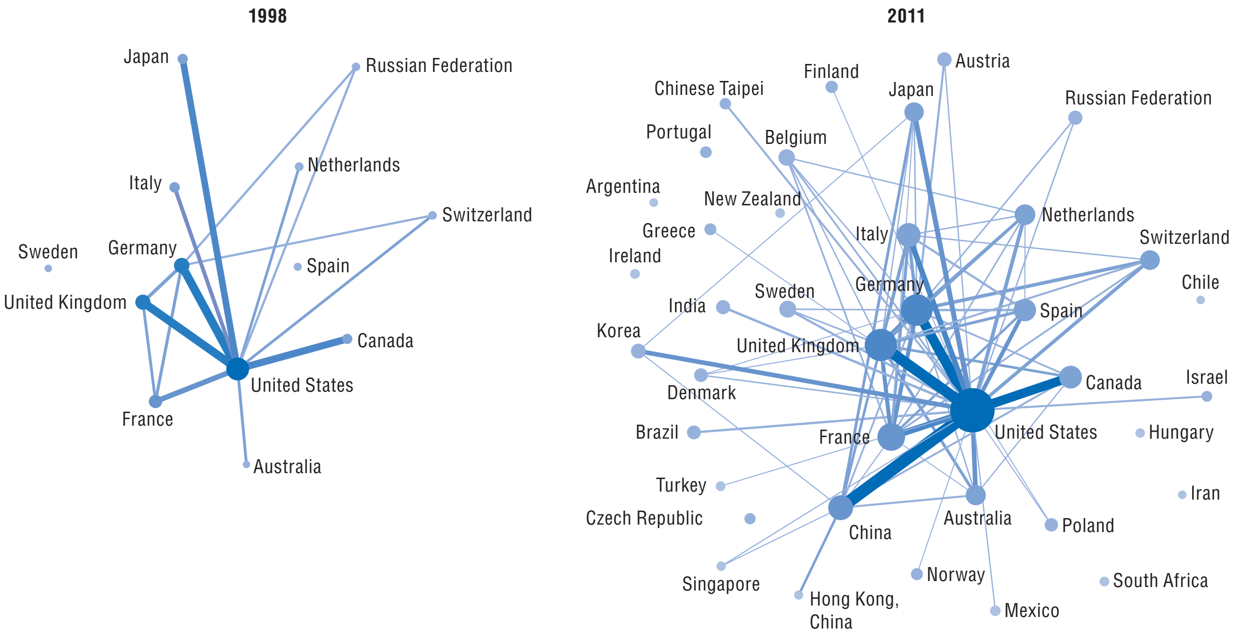
The field of research infrastructures is probably one of the areas that has benefitted most from increased international policy co-ordination in recent years (OECD, 2014c). This is because building and operating large infrastructures requires large amounts of public research funding, providing a strong incentive for collaboration and cost sharing. To facilitate such co-ordination, various policy structures have been set up. The roadmaps of the European Strategy Forum on Research Infrastructures play a crucial role in determining priorities and collaborations within and beyond Europe (for the latest, from March 2016, see ESFRI, 2016). The Carnegie Group of G8 + 5 Science Advisers has established an advisory group tasked with reaching a common understanding on matters such as the governance, funding and management of global large-scale research infrastructures (see the policy profile "Cross-border science, technology and innovation governance arrangements"). The role of such international entities is likely to grow as international co-operation in research deepens.

Internationalisation in research goes beyond large, multinational research infrastructures, of course, and research co-operation and academic mobility have internationalised sharply in recent decades (Figure 3.10). National research policy frameworks are increasingly shaped by a more global context, as STI networks extend beyond national frontiers. Countries, firms, universities and researchers are increasingly organised in open and collaborative networks that connect local research and innovation hubs across frontiers. Ideas, assets and resources concentrate in these pockets of excellence. With new technologies, collaborators in different countries can communicate easily and cheaply, and it is easier than ever to obtain information about research communities in other countries. The global scale of grand challenges could lead to further expansion in international research projects and international co-ordination, as exemplified by recent G7 initiatives on Alzheimer's disease, poverty-related diseases and anti-microbial resistance. Governments will also face pressure to continue efforts to remove barriers in national funding regimes to further international research collaboration. The international mobility of researchers is already high and could increase. Both of these trends could however be countered by wider societal pressures to retrench behind national borders and curb international migration.

Digital technologies are set to radically modify the way science is conducted and the way the results of research are disseminated. A new paradigm of "open science" is emerging, which encompasses: 1) open access to scientific journals; 2) open research data; and 3) open collaboration enabled by ICTs (OECD, 2015a).[4] In parallel, the availability and scale of data available for, and produced by, science have massively increased, as has the ability to interrogate and analyse those data. "Big data" and data-driven research are now ubiquitous across scientific disciplines and open exciting possibilities to address previously inaccessible scientific challenges (see the policy profile "Open science").

Figure 3.10. **International collaboration networks in science are extending and deepening**

Whole counts of internationally co-authored documents



Note: The position of selected economies (nodes) exceeding a minimum collaboration threshold of 10 000 documents is determined by the number of co-authored scientific documents published in 2011. A visualisation algorithm has been applied to the full international collaboration network to represent the linkages in a two-dimensional chart on which distances approximate the combined strength of collaboration forces. Bubble sizes are proportional to the number of scientific collaborations in a given year. The thickness of the lines (edges) between countries represents the intensity of collaboration (number of co-authored documents between each pair). The positions derived for 2011 collaboration data have been applied to 1998 values. New nodes and edges appear in 2011 as they exceed the minimum thresholds.

Source: OECD (2013a), *OECD Science, Technology and Industry Scoreboard 2013: Innovation for Growth*, *http://dx.doi.org/10.1787/sti_scoreboard-2013-en* based on Scopus Custom Data, Elsevier, version 5.2012, June 2013.

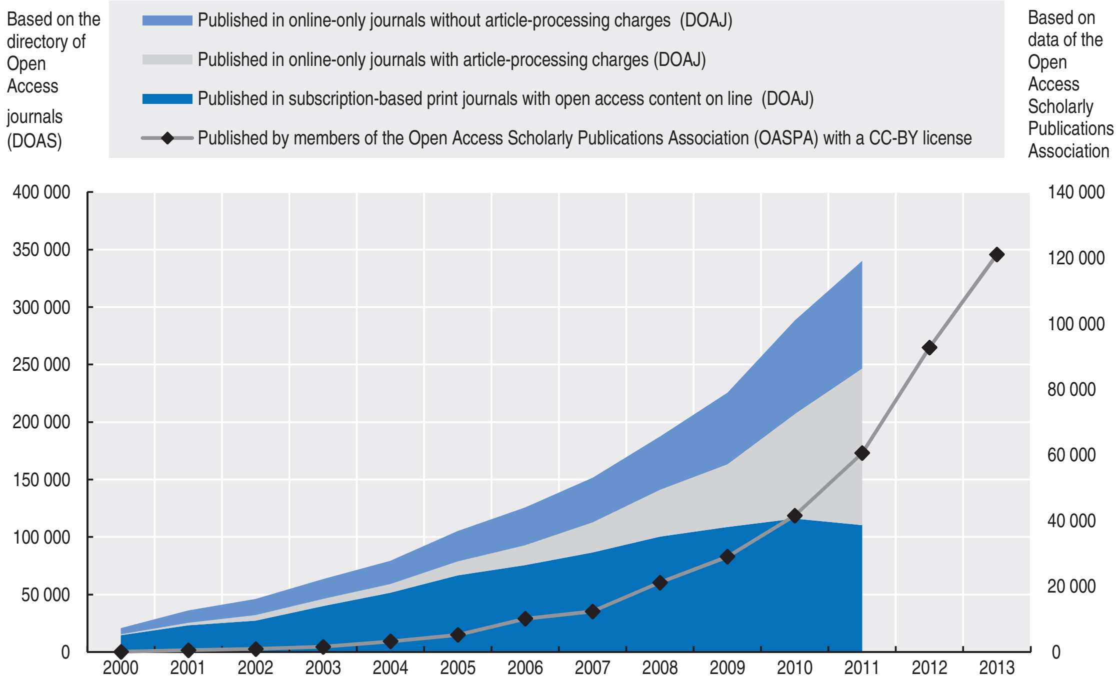
StatLink http://dx.doi.org/10.1787/888933433434

Opening up science is increasingly seen as a means for accelerating research, making it more efficient and promoting the public acceptance of science. There is a general recognition that scientific outputs generated with taxpayer money are public goods and should be made public with a view to increasing their social return. Indeed, one implication of open science is that a given body of data could generate more research and more opportunities for domestic and global participation in the research (OECD, 2014a). And provided that domestic firms have human capital and finance to translate research into usable knowledge, open science could give emerging economies further opportunities to accelerate technological catch-up and possibly leapfrog to nearer the knowledge frontier. There is also some evidence that, as regards open access to scientific publication, sharing data can raise the citation rate of scientific papers (Piwowar, Day and Frisma, 2007; Piwowar and Vision, 2013) and foster good scientific behaviour.

Open access (OA) practices are on the rise (see Figures 3.11 and 3.12), enabled by the low costs of online dissemination. At the same time, the traditional model of publishing in scientific journals has been severely criticised for limiting access to the outputs of publicly-funded scientific research to an exclusive club of higher education and research institutes,

Figure 3.11. **Open access publishing is on the rise**

Number of papers, 2000-13



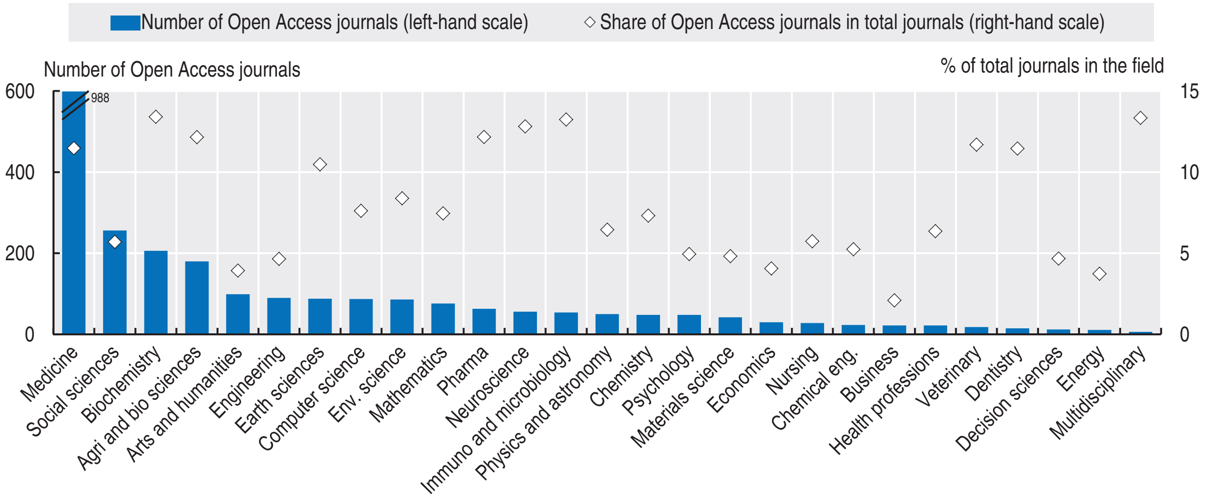
Note: Laakso and Björk describe the results of a study that focuses on measuring the longitudinal development of gold OA publication volume for the years 2000 to 2011. The study is founded on the assumption that the full population of OA journals is listed in the Directory of Open Access Journals (DOAJ). Figures of the Open Access Scholarly Publications Association (OASPA) include a total of 399 854 articles that were published with the CC-BY license by its members during the 2000-13 period. 30% of those articles (120 972) were actually published in 2013 alone. These OASPA numbers include only articles that were published in journals whose entire content is OA, so articles that were published in hybrid OA journals are not included.

Sources: Based on Laakso, M. and B.-C. Björk (2012), "Anatomy of open access publishing: A study of longitudinal development and internal structure", *www.biomedcentral.com/1741-7015/10/124* (cited in OECD, 2015a and accessed 11 June 2015); website of the Open Access Scholarly Publications Association (OASPA), *http://oaspa.org/growth-of-fully-oa-journals-using-a-cc-by-license/* (accessed 30 May 2016).

StatLink http://dx.doi.org/10.1787/888933433448

Figure 3.12. **Open access publishing practices vary across fields of science**

Number of active OA journals and share of OA journals by field of science in OECD countries, 2014



Source: OECD (2015b), *OECD Science, Technology and Industry Scoreboard 2015: Innovation for growth and society*, *http://dx.doi.org/10.1787/sti_scoreboard-2015-en*.

StatLink http://dx.doi.org/10.1787/888933433454 many of which have themselves been protesting the rising costs of journal subscriptions (OECD, 2015a). Two models of OA have emerged: "gold open access" and "green open access" (Box 3.2). Both have pros and cons, and it remains unclear which will emerge in the longer term as the dominant solution.

Box 3.2. **Two main publishing models have emerged to promote open access to scientific articles**

Green open access refers to the "self-archiving" of a published article or the final peer-reviewed manuscript by a researcher after or alongside its publication in a scholarly journal. Public access to such an article can be delayed by a stipulated period of embargo that may vary considerably (generally up to 24 months). Green OA articles do not typically have full reuse rights under a Creative Commons license (CC-BY); pre-print versions deposited online have not been subjected to peer review and the maintenance costs of repositories are substantial. However, articles can be uploaded in multiple venues (from institutional or disciplinary repositories to personal websites) and authors are free to choose their publishing venues. In addition there is no extra cost for authors.

Gold open access or "author pays publishing" refers to a model in which a publication is immediately provided in an OAmode online by the scientific publisher. In this case, the associated costs are shifted from the reader to the author or the research institute to which the author is affiliated. The agencies sponsoring the research may also make provision for the costs of OA. In this model, publishing costs need to be covered and there is limited choice of publishing venue. But the article is immediately available with no embargo periods and typically gets full reuse rights under Creative Commons (CC-BY). In addition, publishers are increasingly offering innovative services and some even offer fee waivers to authors without institutional funding.

Source: OECD (2015a).

Scientists are also rapidly adopting alternative channels to disseminate their work, using blogs, social media and multimedia to share their results. This move is driven by new digital technologies and their burgeoning popularity, as well as by a desire for fast publication that circumvents the slower traditional journal routes and a desire to increase the impact of scientific work by reaching out beyond the limited readership of scientific journals.

As scientific information is increasingly discussed and disseminated in this way, patterns in publishing and recognition are changing. The emergence of new channels of scientific dissemination means that citation databases cover a decreasing part of the scientific literature, which will increasingly challenge their use for measuring scientific output and impact. Still, the dominance of a narrow concept of excellence that relies upon such databases to signal research quality (important for funding and career progression) means traditional publication routes will not quickly disappear, though these are undergoing some changes that speed up publication, allow OA in some circumstances, and embed certain multimedia features. A greater emphasis on social challenges in national research agendas and the concomitant use of public value criteria to assess research impacts will also challenge the current reliance on bibliometrics. Alternative metrics, or altmetrics, as they become accessible from a broader range of digital supports and practices, are likely to be increasingly used alongside more traditional bibliometrics to assess research impacts.

Despite its costs and burden, peer review will remain an important means of assessing research quality. It is likely to undergo some changes – for example, crowdsourced post-publication peer review may emerge as a useful complement to more traditional types of review – but it will remain under close scrutiny, not only because of its costs, but also because of concerns over quality, particularly in light of the apparent lack of reproducibility of much research published in scientific journals.

The digitalisation of science will facilitate greater access to scientific data in the future. Open data has the potential to make the research system more effective and efficient by reducing duplication and by allowing the same data to generate more research (OECD, 2015a). Open data could also help address concerns about the rigour and reproducibility of published scientific results by ensuring OAonline to the underpinning research data.

While the principle of OA to scientific data is already well established in OECD countries, the scope of access still varies greatly (OECD, 2015a). This is because data sets are not as easily identified and defined as scholarly research articles. The diversity of scientific data and differing traditions and standards in their treatment also hamper the accessibility and interoperability of systems. However, these technical issues should be gradually resolved in the next few years, and it is likely that a handful of dominant digital platforms will emerge to support the research system in data sharing (Box 3.3).

Box 3.3. **Platform science: towards a single "operating system of science"?**

As science and research management become increasingly digitised, new opportunities arise for linking datasets covering diverse areas of activity and impact, including research funding, equipment inventories, research data, publications and citations, researcher profiles and social media presence. Could such datasets one day be bundled and vertically integrated into a single "operating system of science" (Heller, 2016)?

The emerging research data infrastructure landscape is made of many different actors, including research performers and funders with their own institutional repositories and information systems, large established academic publishers, but also new firms offering Facebook-like services (notably ResearchGate and Academia.edu). Among recent initiatives to further develop this data infrastructure, the international, government-backed, not-for-profit Open Researcher and Contributor ID (ORCID) project seeks to provide researchers with unique identifiers. These allow better tracking of research and innovation activities (e.g. grant applications, articles submission) and will create new data for analytics. Recognising the benefits of having standardised unique identifiers, funders and publishers around the world are increasingly integrating ORCID into their systems and requirements.

Although there is some overlap between these initiatives, they often draw from different information sources, and no one provider as yet has all the data that would make the others redundant (Heller, 2015). But this could change in the future, and the large academic publishers are perhaps the most advanced in developing, acquiring and integrating different data services. For example:

- The Holtzbrinck Publishing Group, which owns Springer Nature and Digital Science, includes in its portfolio access to online repositories for OA, collaborative writing and publishing software, unique identifiers for research-performing organisations, information management systems to support decision making in research organisations, altmetrics to monitor articles' impact beyond the academic context, and decision support systems for science funders.

Box 3.3. **Platform science: towards a single "operating system of science"?** *(cont.)*

- Another big player is Elsevier Research Intelligence, which offers a variety of services, including a bibliographic database, information management systems to support decision making in universities and PRIs, analytics software for benchmarking and trend analysis, an expert identification tool, and a free reference manager and academic social network.

Could these initiatives led by large academic publishers become the "walled platforms" of science, akin to the likes of Google, Apple, Facebook and Amazon? Or will collaborative, bottom-up and more open alternatives emerge based on open standards and application programming interfaces (APIs)[5] (Heller, 2016)? This is an as yet unanswered question. Open standards can technologically ensure interoperability, data sharing and reuse, but other factors (e.g. network effects, preferential attachment or personal data ownership) could lock users into a single or a few commercial platforms (EC, 2014a).

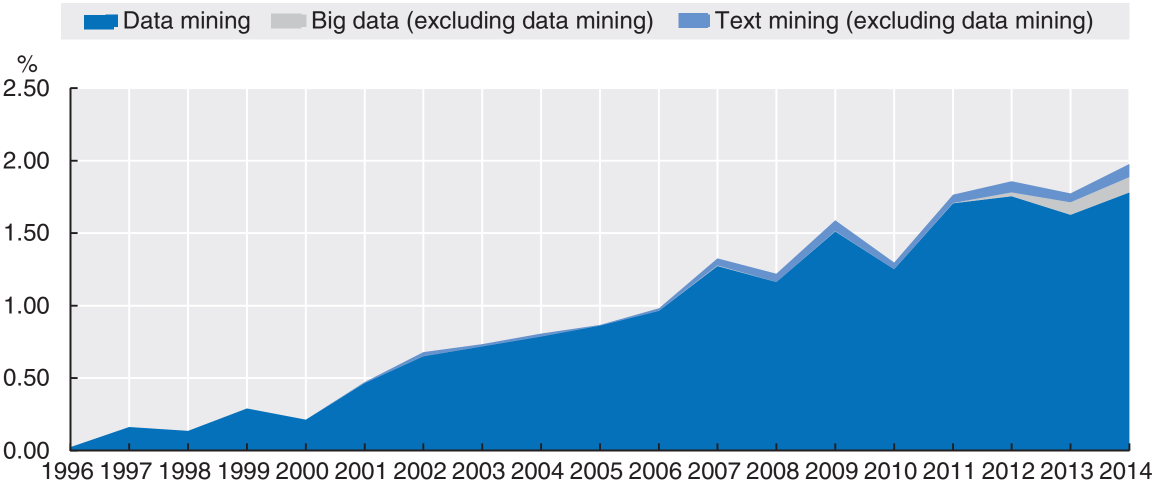
At the same time, many hurdles will remain over the next decade. For example, public research organisations that have incurred most of the storage, preservation and access costs until now will be challenged to find sustainable funding and business models. Legal issues around ownership of large-scale datasets, potentially collected or generated by machines or software providers, and issues around privacy, confidentiality and security will be difficult to resolve, but they will attract considerable policy attention as all spheres of the public research system (including researchers, publishers, funders and policy makers) embrace open data. Sharing results openly online and reusing results and data produced by others also pre-supposes a radical shift in academic culture that will take time to occur and will need to be incentivised. Whilst science is collaborative, it is also intensely competitive. Individual scientists and their institutions are to a very large extent judged by their publication outputs, often using standardised journal bibliometric measures. They therefore have little incentive to share data and experimental material. Mechanisms that accredit the publication of datasets and other collaborative efforts will be essential for promoting open data (see the policy profile "Open science").

Big science creates "big data". The vast expansion of sensors across societies (e.g. through the Internet of Things, the "quantified self" movement and citizen science) and the rapid opening-up of government data will significantly add to this. While the greater availability of data will offer new opportunities and challenges for science, it will also require dedicated infrastructure and skills, which are currently in short supply. In addition there are key challenges in data governance per se. A recent report on big data for advancing dementia research identified seven of those, namely data availability, interoperability, accessibility, ownership, quality, traceability and privacy and security (Deetjen et al., 2015). Novel research fields will develop around data mining, data privacy and security, machine learning, artificial intelligence, database interoperability and related fields. Cheaper processing power, lower equipment costs and massive digitalisation will support faster and more affordable experimentation, while digitalisation will enable replication at a greater speed and with more fidelity (Brynjolfsson and McAfee, 2011). More broadly, public R&D will be increasingly automated, making greater use of robotics and rapid processing, and increasing the scale and efficiency of research.

Pattern-recognition technologies will enhance the analysis of causalities**,** with direct applications in many scientific fields (Figure 3.13). Indeed, much science will be driven by the testing of computer-generated hypotheses based on patterns extracted from massively dimensional databases. Data will increasingly precede the research idea and guide experimental research design (EC, 2014b). The scientific method to date has been built on hypothesis testing. Hypothesis testing is informed by explanatory models which, in turn, are revised through scientific discovery. However, the process and utility of model development is likely to change because, in some fields, the data will contain all objects of interest (data will be comprehensive, not representative). Traditional approaches through hypothesis and "grand theories" development will be complemented by data-driven research that starts with massive amounts of data and may utilise hybrid methodologies and algorithms from different research areas. Change in this direction is already apparent.

Figure 3.13. **Data-driven research is growing rapidly**

Data mining-related scientific articles per thousand articles, 1996-2014



Source: OECD (2014d), *Measuring the Digital Economy: A New Perspective*, *http://dx.doi.org/10.1787/9789264221796-en*, based on ScienceDirect repository, *www.sciencedirect.com*, July.

StatLink http://dx.doi.org/10.1787/888933433466

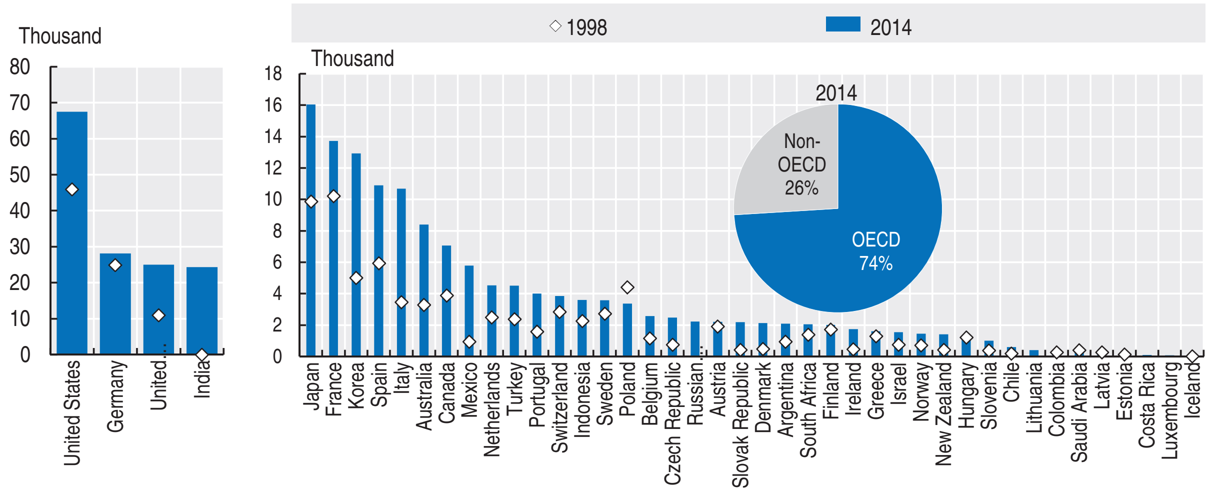
3.6. What will public research careers look like?

The last two decades have seen large increases in the numbers of new doctorates worldwide (Figures 3.14 and 3.15). The United States remains the largest producer of PhDs followed by Germany, the United Kingdom and India and far ahead of Japan. Large emerging economies have greatly expanded their higher education training capacities, including at the most advanced tertiary levels, and non-OECD countries accounted in 2014 for more than a quarter of new doctorates awarded globally. In China in 2014 the share of the relevant age cohort entering doctoral programmes was higher than the average in OECD countries (OECD, 2016c) (see the policy profile "Strengthening education and skills for innovation"). In natural sciences and engineering in particular, China ranked second, between the United States and Germany, in terms of average annual number of doctorates graduating over the 2008-12 period (OECD, 2015b).

Certain scientific fields are more popular among doctorates. About 40% of new doctorates in the OECD area graduate in sciences, engineering and mathematics (STEM), and this percentage increases to 58% of all new graduates if doctorates in health are included (OECD, 2016d). Doctoral programmes are particularly oriented towards natural sciences and engineering in France (59%), Canada (55%) and China (55%).

Figure 3.14. **There are more new doctorates worldwide, including in emerging economies**

Number of doctoral graduates and world's share, all fields, 1998 and 2014



Note: World estimates include countries for which data are available, i.e. 35 OECD countries, Argentina, Colombia, Costa Rica, India, Kazakhstan, the Russian Federation, Saudi Arabia and South Africa. Mexican value for 1998 corresponds to 1999 value.

Source: Based on OECD (2016c), *Education At a Glance 2016, OECD Indicators, http://dx.doi.org/10.1787/eag-2016-en*.

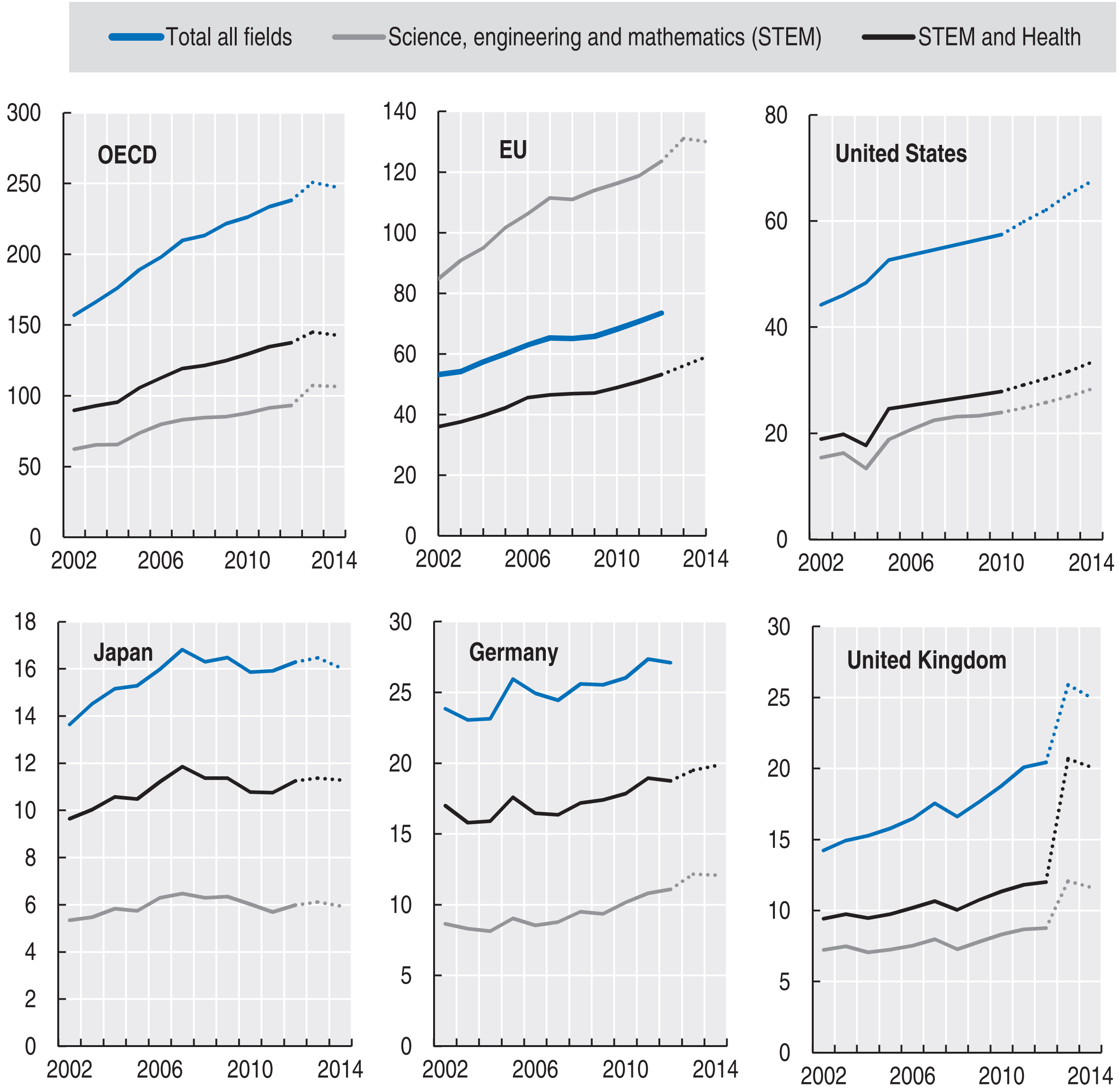
StatLink http://dx.doi.org/10.1787/888933433477

The balance between the supply of and demand for scientists over the next 15 years is uncertain. Population ageing and fears of a disinterest in science among youth have raised concerns among policy makers about the sustainable supply of STI talent, especially in view of the time required for education systems to train new cohorts. A scarcity of relevant skills, if it emerged, could require a greater reliance on sources of talent from abroad, especially from emerging and developing economies with more favourable demographics. However, as research systems in these economies further develop, the global competition for talent is likely to intensify.

On the other hand, falling public investments and growing automation in laboratories could reduce demand for new researchers. Until recently, growth in PhD numbers was viewed as overwhelmingly positive and actively encouraged by policy. Furthermore, the erosion of core funding in universities and public labs and its replacement with more short-term competitive project-based funding created significant demand for relatively mobile and cheap PhD students and post-doctoral researchers employed on short-term contracts. But this era may now be drawing to a close, as many doctorate holders face difficulties finding work that matches their high level of skills. There are also some signs of a slowdown in STEM doctorate graduation in recent years, in relative terms as compared to the number of new graduates in other fields, especially in the largest doctoral education systems (Figure 3.15) (see the policy profile "Building a science and innovation culture").

Figure 3.15. **The supply of doctorates in science and engineering shows some signs of slowdown**

Number of doctoral graduates in STEM and health in major supplying systems, thousand, 2000-14



Source: Based on OECD (2016d), *OECD Education and Skills Database*, extracted from OECD.Stat on 23 Septembre 2016.

StatLink http://dx.doi.org/10.1787/888933433485

A “dual labour market” has emerged in universities and PRIs as a result of these dynamics, consisting on the one hand of relatively well-paid established researchers who often have permanent civil servant or public employee contracts, and on the other hand a growing number of cheaper temporary staff recruited with soft money at centres of excellence or on competitively-funded research projects (Kergroach and Cervantes, 2006). A recent survey of 38 EU and EU-partner countries shows a persisting duality, with a significant proportion of researchers in the higher education sector employed on fixed-term contracts, or no contracts at all, the situation being most pronounced during early career stages (Deloitte, 2014). In 2012, the proportion of researchers with “no contract at all” or on a less-than-one-year contract was ten times higher among PhD students and young graduates

(31%) than at the latest research career stages (3%). Almost 90% of PhD researchers were in precarious working conditions with no or less-than-two-year contractual horizons, while 90% of leading senior researchers were on permanent positions. This duality has created problems for the individuals involved, who have little long-term job security and increasingly face few opportunities to obtain permanent or tenured positions. Beyond issues of contract status, these individuals also have less rewarding remuneration packages, lower access to research funding, training and career development programmes and, overall, weaker career prospects. It is not unusual for researchers to do two or three post-doctoral positions before attaining a permanent position in their late-30s – assuming they have remained in the profession for that long. In fact, an increasing number are edged out of research careers, which raises questions over the return to costly public investments in their training. The duration of PhD training is still quite long in a number of countries and means that the social and private costs of producing new graduates is high; the long duration also reduces the speed at which the system can respond to changes in demand.

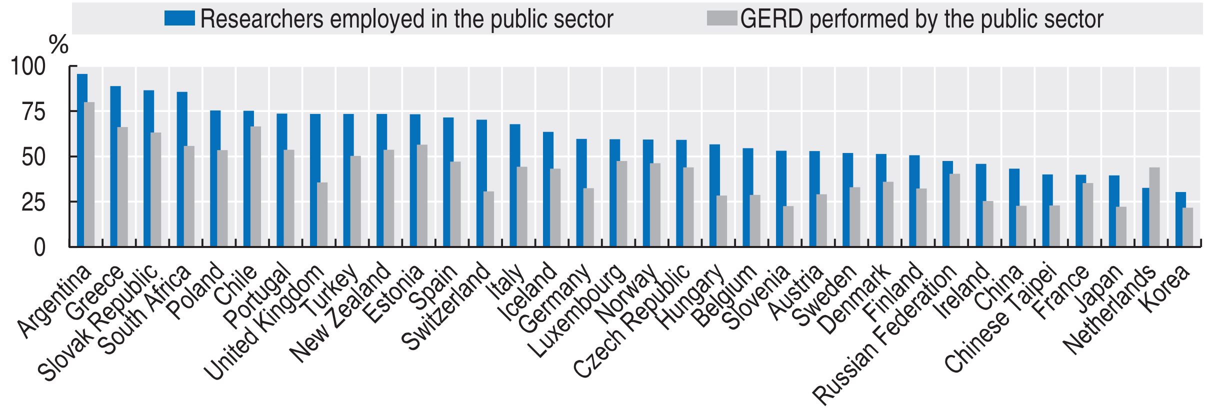
In summary, while project-based competitive funding remains the dominant mode of research funding, there will continue to be strong rigidities in the labour market for established researchers, and short-term employment contracts will continue to dominate early-to-mid-career paths. But the substantial growth in PhD and postdoc positions seen over the last few decades has recently come under close scrutiny as many struggle to establish long-term careers in science. Yet a decline in the number of PhDs and postdocs flowing through the system would cause problems for public research labs, whose current set-up depends on a constant stream of PhD students and post-doctoral researchers to do much of the work.

Given that many PhDs (and increasingly, postdocs) are leaving the research profession, there is growing recognition that they should receive training to provide transferable skills and exposure to industry and other employment sectors. Still, in many countries, there is scope for matching PhD training more closely with market needs and diversifying career paths through internships, as well as allowing the portability of PhD fellowships to industry. This need for better matching will attract greater policy attention in coming years. Training new researchers through the PhD and postdoc process will therefore need to broaden because many are discontinuing public R&D careers and moving into other parts of the economy. However, this shift will likely meet resistance from laboratory heads who rely heavily on over-worked PhD students and postdocs to perform much of the day-to-day research that is carried out in their labs. In the absence of inducements or a wider cultural change, they have few incentives to allow their staff the time to participate in non-core laboratory research.

As major employers of R&D personnel, and through performance agreements with universities and PRIs, governments can influence research careers. The public sector accounts for a disproportionate share of employed researchers, even in countries where most R&D is performed by the business sector (Figure 3.16).[6] Governments also have capacity to intervene upstream, through the redesign of doctoral programmes that are increasingly a key stepping stone in research careers (Cervantes, Kergroach and Nieto, forthcoming). However, their capacity to make research careers more attractive, as well as the policy instruments at their disposal for that purpose, are likely to evolve as more R&D is performed by the business sector, policies to encourage the recruitment of researchers in the private sector bear fruits, and more researchers are employed in non-public organisations.

Figure 3.16. **The public sector accounts for a disproportionate share of employed researchers**

Share of GERD and researchers respectively performed and employed in the public sector, 2014 or latest year available

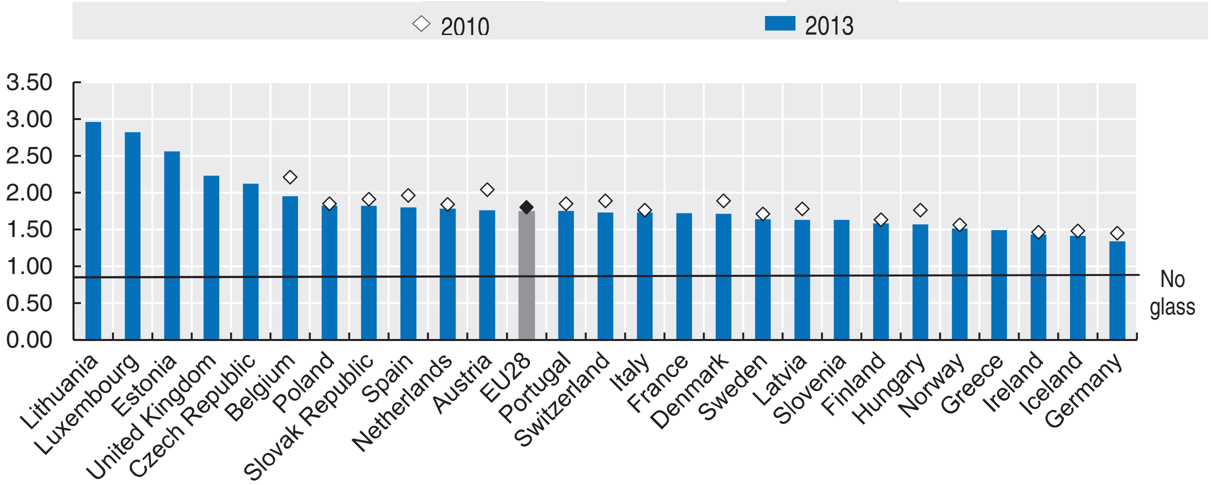


Source: Based on OECD (2016a), *OECD Main Science and Technology Indicators (MSTI) Database*, June, *www.oecd.org/sti/msti*.

StatLink http://dx.doi.org/10.1787/888933433495

Figure 3.17. **Women remain away from top academic positions in Europe**

"Glass ceiling" index, 2010 and 2013



Note: The Glass Ceiling Index (GCI) is a relative index comparing the proportion of women in academia (grades A, B, and C) with the proportion of women in top academic positions (grade A positions, equivalent to full professors in most countries) in a given year. The GCI can range from 0 to infinity. A GCI of 1 indicates that there is no difference between women and men in terms of their chances of being promoted. A score of less than 1 means that women are more represented at the grade A level than in academia generally (grades A, B, and C) and a GCI score of more than 1 indicates the presence of a glass ceiling effect, meaning that women are less represented in grade A positions than in academia generally (grades A, B, and C). In other words, the interpretation of the GCI is that the higher the value, the stronger the glass ceiling effect and the more difficult it is for women to move into a higher position.

Source: EC (2016), *SHE Figures 2015*, *https://ec.europa.eu/research/swafs/pdf/pub_gender_equality/she_figures_2015-final.pdf* (accessed 22 April 2016).

StatLink http://dx.doi.org/10.1787/888933433507

Following gradual improvements in recent years (Figure 3.17), the public R&D workforce will become more female, and more women will hold senior positions. This change will continue to occur slowly, however, despite sustained policy attention. Barriers to female participation in science will likely persist. Gender stereotypes are hard to change; workplace practices will remain insufficiently family-friendly, and discriminating selection and promotion arrangements (e.g. exclusively or predominantly male boards, procedures that disregard activities women are more widely represented in, like teaching), will still exist. In many countries, women still face a glass ceiling in the research profession. Even though they outnumber men at bachelor and masters levels of education, they are considerably less likely to enter advanced programmes in science, are less likely to occupy senior academic positions and are even less likely to head a university or PRI (Figure 3.17).

Digital and open science will require the deployment of new skills. Data-related skills development will be essential for making efficient use of new scientific datasets, tools and methods. As these tools will become pervasive in all scientific disciplines, including the humanities, there may be a significant need for re-training researchers. The more open nature of science and the closer links science is building with industry will require researchers to reinforce their "soft" skills, including in project management, team-working, and business and intellectual property awareness. Recent surveys on the behaviour of scientists reveal that not all researchers are necessarily aware of the possibilities offered by open science, for example (OECD, 2015a).

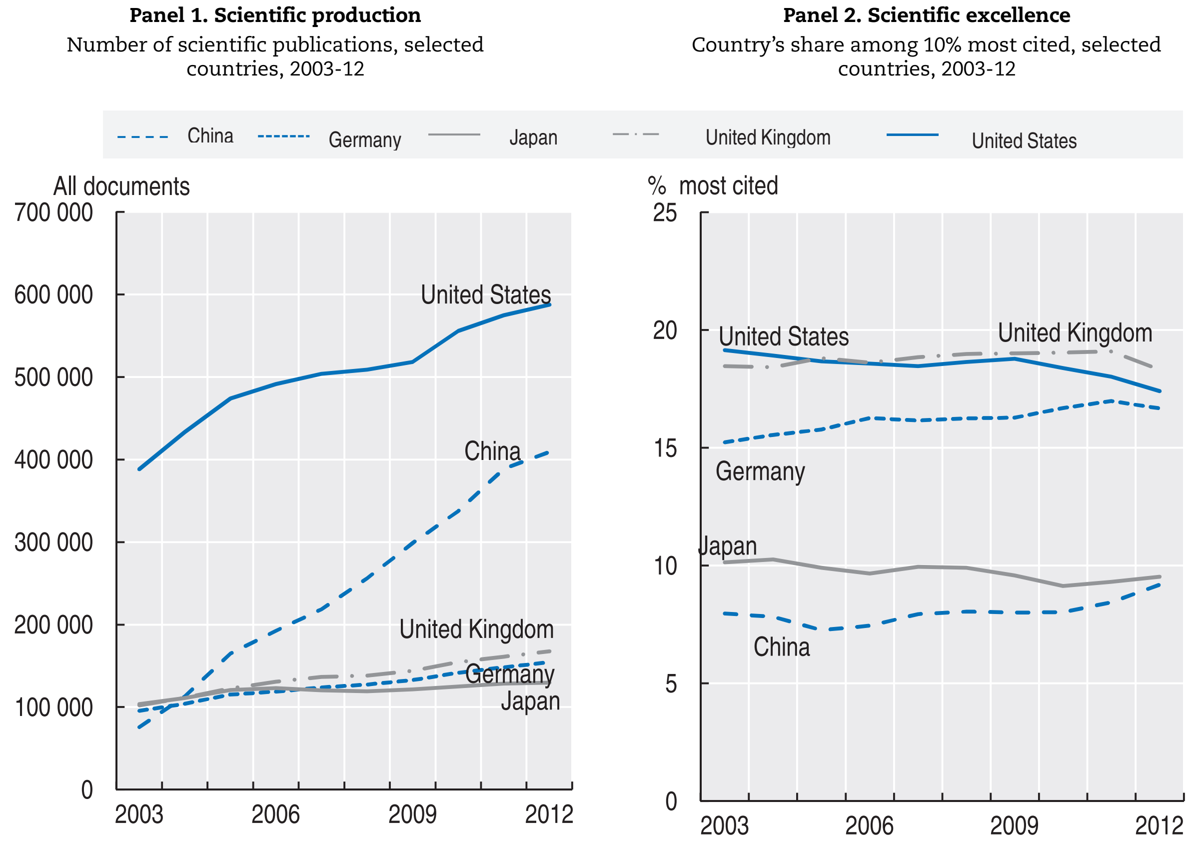
3.7. What outputs and impacts will be expected of public research?

The increased investment in public research over the last 15 years or so has also led to a growing number of scientific publications (Figure 3.18, Panels 1 and 2). This has been especially so for China, where the number of publications over the ten-year period 2003-12 increased more than four-fold. China's share of publications among the 10% most cited rose only slightly over the same period and, though roughly on a par with Japan's share, remains well below the United States, the United Kingdom and Germany. Raising research excellence will remain a major challenge for China in the medium term, and matching the citation rates of the long-established scientific powers is most likely some way off. However, Germany shows that it is possible to increase citation rates, though its expansion of scientific output is on a far more modest scale than China's for the same period.[7]

Parallel to and in synergy with the evolution of strategic research for major societal challenges, the global trend towards more competitive funding has seen most governments introduce performance-based elements in core institutional funding and move towards more contractual arrangements (OECD, 2014e). Accordingly, governments have resorted to using tools such as performance agreements, new funding mechanisms and performance metrics to orient public research activities towards national research priorities and to strengthen scientific performance (OECD, 2014a). Further developments along these lines can be expected, though this will likely meet challenges and even resistance. The limits of performance metrics, including what they fail to measure, the costs of the associated data collection, and the scope for gaming measurement systems and adversely distorting behaviours, means that their use will continue to be contested (Box 3.4).

The commercialisation of public research has become a major goal of national S&T policies over the last few decades and a key function of universities and public labs (OECD, 2013b). A growing number of policy initiatives aim to foster co-operation between industry and science and accelerate the transfer of public research results to society, while a growing number of research system intermediaries aim to smooth and improve transfers (e.g. technology transfer offices, patent funds, intellectual property brokers, etc.). These efforts have only been partially successful, in part because of their inappropriateness in many settings where knowledge and technology transfer occur more effectively through other channels. The very rapid growth in patenting seen in the last 15 years has already begun to tail-off as universities and public labs become more strategic and selective in building their intellectual property portfolios. The mixed success of university-owned

Figure 3.18. **Scientific production has increased worldwide but rankings of excellence are slower to change**



Panel 1. Scientific production

Number of scientific publications, selected countries, 2003-12

Panel 2. Scientific excellence

Country's share among 10% most cited, selected countries, 2003-12

Note: Scientific production/Output/Number of documents is the total number of documents published in scholarly journals indexed in Scopus (whole counts of all document types by author affiliation). Excellence indicates the amount (in %) of an institution's scientific output included in the set of 10% of the most-cited papers in their respective scientific fields. It functions as a measure of high-quality output of research institutions. Albeit imperfect, this indicator is commonly used to capture research excellence.

Source: OECD (2015b), *OECD Science, Technology and Industry Scoreboard: Innovation for growth and society*, *http://dx.doi.org/10.1787/sti_scoreboard-2015-en.*

StatLink http://dx.doi.org/10.1787/888933433519

Box 3.4. **Paving the way for better metrics and more appropriate use**

While recent years have seen the use of science and innovation metrics proliferate, there is increasing alarm among scientometricians, scientists and research administrators at the pervasive misapplication of indicators in research assessment (Hicks et al., 2015). Among the most frequent criticisms are the skewed nature of citation distributions across journals or fields of science, and the poor relevance of journal impact for assessing an individual's or a team's merit. Likewise, there is evidence of a rise in strategic citation practices (e.g. self-citation, influence of interpersonal networks).

Promoting the idea that research should be assessed on its own merits, three recent landmark initiatives set out several recommendations for improving the use of metrics in research assessment:

The *San Francisco Declaration on Research Assessment* (2012) calls on all research actors to avoid using journal-based metrics as a surrogate measure for the quality of scientists or their work. For funding agencies particularly, the Declaration calls on them to consider the

Box 3.4. **Paving the way for better metrics and more appropriate use** *(cont.)*

value and impact of all research outputs and to use a broad range of impact measures, including qualitative indicators. Both individuals and organisations are invited to indicate their support by adding their names to the Declaration (*www.ascb.org/dora*), which had more than 12 000 signees by the end of 2015.

The Leiden Manifesto (2015) is a compendium of ten principles for metrics-based research assessment that builds on the idea that research assessment is increasingly implemented by organisations without knowledge of, or advice on, good practice and the interpretation of metrics. The Manifesto's ten principles, which have been published in the leading journal *Nature* (Hicks et al., 2015), stress the complementarity of quantitative evaluation and qualitative expert assessment; recognise the idiosyncrasies of performance conditions and the need to adjust evaluation accordingly; encourage protection of locally-relevant research (e.g. non-English literature); highlight the desirability of open and transparent evaluation practices, as well as the importance of their integrity and accuracy; call for better taking into account well-known biases in publication and citation; suggest to disseminate evaluation results in a precise and informed manner to avoid potential negative effects on research systems as a whole (e.g. gaming, goal displacement); and, finally, recall the need to regularly revise and update metrics to reflect shifts in research missions and assessment goals.

The Metric Tide (2015) provides recommendations on research assessment on the basis of a UK review of the potential future roles that quantitative indicators could play in the governance, assessment and management of research. The review found that a "variable geometry" of expert judgement, quantitative indicators and qualitative measures that respect research diversity is necessary for robust research assessment. The Metric Tide's recommendations also underpin the notion of "responsible metrics", which would fit criteria of robustness, humility, transparency, diversity and reflexivity. More recently, an independent review of the UK Research Excellence Framework stressed that, with the exception of some sub-disciplines, metrics capture only some dimensions of output quality (UK Department for Business, Energy and Industrial Strategy, 2016). Its recommendations highlight the need for widening and deepening the notion of impact to include influence on public engagement, culture and teaching as well as policy and applications more generally; the under-representation of interdisciplinary research; and the benefits of a more productive use of assessment data and insights for both institutions and the United Kingdom as a whole.

While it will no doubt prove difficult for the research community to wean itself off using traditional bibliometrics, these three initiatives may mark a turning point towards more varied and robust assessment arrangements over the next ten years.

Sources: ASCB (2012); Hicks et al. (2015); UK Department for Business, Energy and Industrial Strategy (2016); Wilsdon et al. (2015).

technology transfer offices over the last 15 years or so has also seen new arrangements emerge, including technology transfer "platforms" that are both cross-institutional, such as the Sociétés d'accélération du transfert de technologies in France, and specialised in particular areas of research or technology.

Policy will take an increasingly broad approach to the socio-economic benefits of public research over the next 15 years, which will coincide with the deeper and more extensive engagement of universities and public labs with society, both locally and further afield. As research and innovation landscapes become more open and complex – with more actors and interactions – universities and PRIs will further develop research relationships with the likes of patient groups, “maker communities” and environmental groups. Student entrepreneurship is also likely to grow, supported by a broadening of PhD training curricula.

3.8. What will public research policy and governance look like?

The trends and issues outlined in this chapter all have implications for STI policy and governance arrangements. Indeed, the expected changes in the public research system over the next 10-15 years will demand a policy response and will be shaped by policy changes. Funding arrangements between the government, on the one hand, and universities and PRIs, on the other, will continue to be both the most important channel for delivering public research policy and a major driver of change in the public research landscape. Regulation and governance arrangements will also play crucial roles.

The final part of the chapter considers four trends that are specific to future STI policy practices. The first trend is the growing influence of so-called “responsible research and innovation”, which places greater emphasis on broader public engagement in STI policymaking. The second trend concerns the rise of design thinking and experimentation in policy formulation and delivery, with a view to creating a more agile STI policy. The third trend is the growing digitalisation of STI policy, including the opportunities from big data analytics for more evidence-based policy. Staying with the theme of evidence, the fourth trend concerns changing arrangements for scientific advice to policy.

The risk and ethical implications of research and technological change will most likely lead to a more active engagement of wider society with science. Public values will become more prominent as criteria for assessing research. The greater attention paid to the ethical and societal dimensions of research is already being reflected in the framing of more “responsible research and innovation” (RRI) policies. These seem to reflect a shift away from simply educating the public, to better aligning STI with social goals. One way governments have been doing this is to find ways to engage the public early and often in the process of research and to feed that into STI policy (see the policy profile “Public engagement in STI policy”). In the last few years, a number of countries have put in place participatory and bottom-up approaches to setting STI strategies (EC/OECD, forthcoming). Through this new RRI approach, governments intend to anticipate and assess the potential implications and societal expectations associated with research and innovation, with the aim of making research and innovation more inclusive and sustainable. Operationalising this vision in new practices and governance arrangements will nevertheless remain a major challenge. Furthermore, scientists’ and policy makers’ fears that RRI will hamper and delay scientific progress and weaken the competitive capacity of national research institutes will continue to be a powerful force shaping future moves in this direction.

As part of a movement towards public sector innovation (Box 3.5), design thinking and experimentation will become more commonplace in policy-making and delivery as governments seek to become more agile and innovative. Piloting, prototyping and other experimental design tools will be increasingly used to implement new approaches safely and to minimise the risks associated with policy innovation. Such arrangements will support learning and allow for “fast-failure” before significant resources are invested. Learning from pioneers such as Denmark’s Mindlab and the United Kingdom’s Policy Lab, many countries will set up “policy lab” type units that apply design concepts to public

Box 3.5. **Public sector innovation**

In recent years, innovation has become a more significant imperative in policy programmes and initiatives. Experimentation is increasingly embedded in policy design and service delivery as a way to better keep up with increasing complexity and user expectations. New tools and approaches – from data analytics to prototyping and design thinking – are being applied across the public sector to manage uncertainty, and to respond to changing user demands for personalised digital services and convenient automatised processes that rival the efficiency and effectiveness of industry. Around the world, public innovators are being celebrated through events, awards and prizes.

At the same time, the promise of public sector innovation will continue to face challenges. While progress has been made, gaps remain. Innovators across the world are still fighting cumbersome administrative procedures and cultures that inhibit action. Professionals lack direct access to expertise and tools for innovation. Managers are left with the difficult task of selecting, recruiting and hiring public servants with the right skills and attitudes. And there is limited understanding of risk, and its management, which inhibits innovators in the public sector.

Source: Abridged from Daglio, M. (2016), "Public Sector Innovation: the Journey Continues…", OPSI blogpost *www.oecd.org/governance/observatory-public-sector-innovation/blog/page/publicsectorinnovationthejourneycontinues.htm*.

services. Enacting these changes will not be easy. Notable challenges include the need to strengthen the skill sets of public servants to monitor, evaluate and adjust experiments; and, in an era of constrained public spending, to ensure resources and capabilities are available for the public sector to innovate (Daglio, Gerson and Kitchen, 2014).

Recent trends in the codification and opening of government data will provide opportunities to better understand how science and innovation take place and to trace STI policy decisions and impacts. New digital technologies will support new data infrastructures and further open the dissemination, linking and re-use of various types of data. Such infrastructures will affect the practices and organisation of government. They will, for example, offer new evaluation possibilities through better linking of inputs and outputs, and will also offer the prospect of better cross-government co-ordination as well as participation by non-state actors through information and data sharing.

Many countries already implement quantitative and qualitative data infrastructures to support more evidence-based STI policy making. Some of these are initiated as part of broader open government and big data initiatives. Others are more specific to the STI policy domain, such as the various "science of/for science policy"-type projects started over the past five to ten years (see the policy profile "Evaluation and impact assessment of STI Policies"). New commercial and non-profit infrastructures are also increasingly present and may play a pivotal role in future STI data infrastructure developments. The roles of national statistical organisations will likely evolve as the science and innovation data landscape fragments among several government agencies and private repositories.

Realising the potential of new STI data infrastructures faces numerous challenges, however. Among these challenges are the need to develop standards that will allow for the disambiguation and linking of unstructured data.[8] Leveraging the potential of administrative data for science and innovation policy will also require new specific skills and capacities, such as data analytics, among civil servants as well as a culture of data use across the policy cycle. And new approaches will be needed to facilitate the visualisation and understanding of data.

The scientific community will continue to be called upon to provide evidence and advice to government policy-makers across a range of issues, from short-term public health emergencies to longer-term challenges, such as population ageing and climate change. However, science advisory structures will likely undergo some overhaul if, as seems likely, they are increasingly called upon to deal with issues of a global, multidimensional, fast-evolving and complex nature.

The moves towards more responsible research policies will likely open the academic enterprise to closer surveillance and critique (see the policy profile “Building a science and innovation culture”). This may put additional pressure on science to provide clear and unambiguous answers and solutions, though it is perhaps just as likely that it will not, since involved citizens may come to better appreciate the provisional nature of much scientific evidence. Science advice could become more widely debated, and contested in some instances, especially on sensitive topics like genetically modified foods, childhood vaccinations, shale gas drilling and gene editing. As scientific evidence, societal values and beliefs, economic considerations and policy-decisions overlap and diverge, strong tensions may arise (OECD, 2015c).

The international dimension of scientific advice will also be reinforced through new or renewed international structures and greater internationalisation of existing national arrangements. For instance, the role of international advisory bodies will continue to expand to reflect the growing number of transnational issues (e.g. climate change, water-energy-food security, epidemics, etc.) in which science, technology and society are tightly intertwined. In parallel, governments will encourage stronger connections between their scientific advisory structures and international counterparts, with a view to better exchanging data, information, expertise and good practices (OECD, 2015c).

Notes

1. Global gross R&D expenditure (GERD) is estimated by the sum of GERD performed by OECD countries, Argentina, the People’s Republic of China, Chinese Taipei, Colombia, Latvia, Lithuania, Malta, Romania, the Russian Federation and Singapore. The estimates made for Argentina, Australia, New Zealand, the Russian Federation, Singapore, South Africa, Switzerland and the United States are in 2014 constant prices. In 2010 constant prices, the world estimate would amount therefore to approximately USD 792 billion PPP in 2000 and USD 1.54 trillion PPP in 2014.
2. Government budget appropriations or outlays for R&D (GBAORD) measure the funds that governments allocate to R&D for various socioeconomic objectives. These are defined according to the primary objective of the funder. In some countries, a medical science component can be identified from non-orientated funds for research, including from general university funds. In these cases, R&D budgets dedicated to health may underestimate total government funding of health-related R&D. Efforts to account for funding of medical sciences via non-oriented research and general university funds could help provide a more complete picture. Such analysis has been intended in the latest OECD STI Scoreboard (OECD, 2015b).
3. According to Sarewitz (2012), “Although the NIH is in some respects a mission agency, its priorities, its work force and the image it has cultivated focus on fundamental science”.
4. Other aspects of an open science system include post-publication peer review, open research notebooks, open source software, citizen science and the crowdfunding of research (OECD, 2015a).
5. An API (application programming interface) facilitates the sharing of content and data between applications, so that content that is created in one place can be dynamically posted and updated in multiple locations on the web.

6. OECD survey data collected in 2009 across 16 OECD countries showed that the main sector of employment for doctorate holders working as researchers was often higher education, signalling doctorates' preference to pursue academic careers (Auriol *et al.*, 2013).
7. This expansion is still considerable though, and similar rates of growth in scientific publications have occurred in the other major scientific powers as well. Assuming that the vast majority of scientific publications emanate from public research, this growth outstrips the growth in public research budgets and researchers and reflects changes in publication behaviour that have been evident for at least two decades. This is perhaps best illustrated with the data from the United Kingdom, where public research budgets have barely grown while at the same time the number of scientific publications has risen considerably. A performance culture that values scientific publication largely explains these figures, but there is surely a limit to the number of scientific publications.
8. Unstructured data are by definition not structured, i.e. not organised in a pre-defined manner and along a pre-defined model. They are typically not stored in relational databases and are therefore difficult to search, link or analyse.

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