

## Fostering Science and Innovation in the Digital Age

Digitalisation is reshaping all stages of science, from agenda setting, to experimentation, knowledge sharing and public engagement. Digital technology is enabling a new paradigm of open science, which has three main pillars: open access to scientific publications and information; enhanced access to research data; and, broader engagement with stakeholders. Digital technology is also enlarging the process of discovery.

Four trends are also evident regarding innovation and digitalisation in firms. First, **data is a key input for innovation**. Data is helping firms explore new areas of product and service development, gain insights on market trends, optimise production and distribution, and adjust products and services to market demand. Second, **digitalisation enables services innovation**. For example, the Internet of Things has enabled predictive maintenance services. Third, **digital innovations (such as 3D printing) speed innovation cycles**. These innovations can accelerate product design, prototyping and testing, and enable the launch of product beta versions that rapidly incorporate consumer feedback. And fourth, **innovation is becoming more collaborative**. Collaboration helps share the costs and reduce the risks of digital innovation, and is itself made easier by lowered costs of communication. All of the above developments, in science and in firms, create new emphases for policy (OECD, forthcoming).

### Key recommendations

- Advance the transition to open science, which could make science more efficient and effective and speed the translation of research findings into innovation and socio-economic benefits. Ensure access to data for innovation, balancing economic, privacy and intellectual property concerns. Facilitate access to the large volumes of data needed to train AI systems, and prepare to address emerging issues in data policy.
- Develop digital skills, creating institutions and incentives that permit rapid responses to changing skills demand. Ensure the availability of complementary infrastructures, such as high-performance computing (HPC) and broadband networks (especially fibre-optic connectivity, which is essential to Industry 4.0). Commit to public sector research, which has been the source of key digital technologies, and consider using well-structured public-private partnerships in critical fields that exceed the research capacities of even the largest firms.
- Foster the diffusion of digital technologies, as most countries, regions and companies are primarily technology users, and diffusion is often slow.
- Develop technology- and sector-specific expertise in government. Optimise digital information systems to support science and innovation policies. And consider experimenting with new ideas on how digital technologies, such as blockchain, might benefit science and innovation processes.

### The transition to open science

Open science could make science more efficient and effective and speed the translation of research findings into innovation and socio-economic benefits. But this shift also requires adjustments to policy.

#### Accessing scientific information

The volume of scientific data, information and publications is enormous and growing rapidly. The average scientist reads about 250 papers a year, but more than 26 million peer-reviewed papers exist in biomedical science alone. Scientific research has traditionally been published in specialised journals, after peer review. New open access publishing models are making access to scientific information easier. However, in this new environment it is unclear how

editorial and peer review processes will work and how the academic record will be maintained over time. **Research funders should revisit mandates or incentives that might inadvertently encourage publication in journals that fail to provide adequate quality control.**

The quality of scientific output is also in question. Freedman, Cockburn and Simcoe (2015) estimated that in the United States USD 28 billion a year is wasted on unreproducible preclinical research. Digital tools can help. For example, researchers are increasingly using tools such as artificial intelligence (AI) to scrutinise suspicious scientific research and identify falsified data (Sankaran, 2018). **Such tools depend on the broad adoption of standards and unique digital identifiers, which policy can facilitate.**

Many science funders mandate open access publication, but academic careers, and in some cases institutional funding, often depend on publishing in high impact, pay-for-access, journals. **Mandates from research funders need to be accompanied by changes to incentives and evaluation systems. A stronger focus on article-based metrics rather than journal impact factors is one way forward.**

### Enhancing access to research data

The OECD first advocated for greater access to data from publically funded research in 2006 (OECD, 2007). Since then, tools to enable greater access have improved, and guidelines and principles have been widely adopted. Nevertheless, obstacles still limit access to scientific data:

- **The costs of data management are increasing, straining research budgets.** Science funders should treat data repositories as a part of research infrastructure.
- **A lack of policy coherence and trust hinders data sharing across borders.** To share public research data common legal and ethical frameworks are necessary.
- **Science must adapt its governance and review mechanisms to changing privacy and ethical concerns.** For example, new information and communication technologies (ICTs) make the anonymisation of personal research data more difficult. Transparent, accountable and suitably empowered governance mechanisms, such as Institutional Review Boards, should oversee research conducted with new forms of personal data (OECD, 2016).
- **Strategic planning and co-operation are required to build and provide access to cyber-infrastructure internationally.** To develop community standards, technical solutions and social networks, global bodies such as the Research Data Alliance can help.
- **The skills needed to gather, curate and analyse data are scarce.** New career structures and professions – such as “data stewards” – need to be developed.

### Broadening engagement in science

Digitalisation is opening participation in science to patient groups, NGOs, industry, policy makers and others. It is also expanding “citizen science”, whereby scientific research is conducted through ICT-enabled open collaborative projects. For instance, by playing a video game – Eyewire – 265 000 people have helped neuro-scientists at Princeton University develop thousands of uniquely detailed maps of neurons (Princeton University, 2018). Broader engagement can enhance the entire research process, from agenda setting to co-production of research and dissemination of scientific information. Perhaps the most critical form of enlarged engagement is the setting of priorities for research (OECD, 2017a).

### Artificial intelligence in science and business

Three key technological developments have driven the recent growth in AI performance and research (Figure 1): vastly improved computer hardware, vastly increased data availability and vastly improved AI software (with scientists now having access to open-source AI code) (OECD, 2018a).

AI has the potential to increase the productivity of science at a time when some evidence suggests research productivity may be falling. AI is being applied to all phases of the scientific process, including the automated extraction of information from scientific literature, experimentation (the pharmaceutical industry commonly uses automated high-throughput platforms for drug design), large-scale data collection, and optimising experimental design. Today, AI is regularly the subject of papers in the most prestigious scientific journals. AI is also being combined with robotic systems to automate some aspects of science, especially in disciplines that require intensive experimentation, such as molecular biology (OECD, 2018a).

Expert systems, a form of AI that draws on pre-programmed expert knowledge, have been used in industrial processes for close to four decades. But with the advent of deep learning using artificial neural networks – the main source of recent progress in AI – AI is ready to be applied in most industrial activities, from optimising multi-machine systems, to enhancing industrial research. Companies working to automate the machine learning process will also spur AI in production.

### Policy for AI in science

As AI contributes increasingly to science, the importance of some areas of policy will grow. These include policies that affect access to data (such as standardisation for machine readability of scientific datasets), skills (see below), and HPC (computational resources, essential to leading-edge research in AI, can be extremely expensive). The increasing prominence of AI in discovery is also raising new, and as yet unanswered, policy questions such as: Should machines be included in academic citations? and Will intellectual property systems need adjustment in a world in which machines can invent?

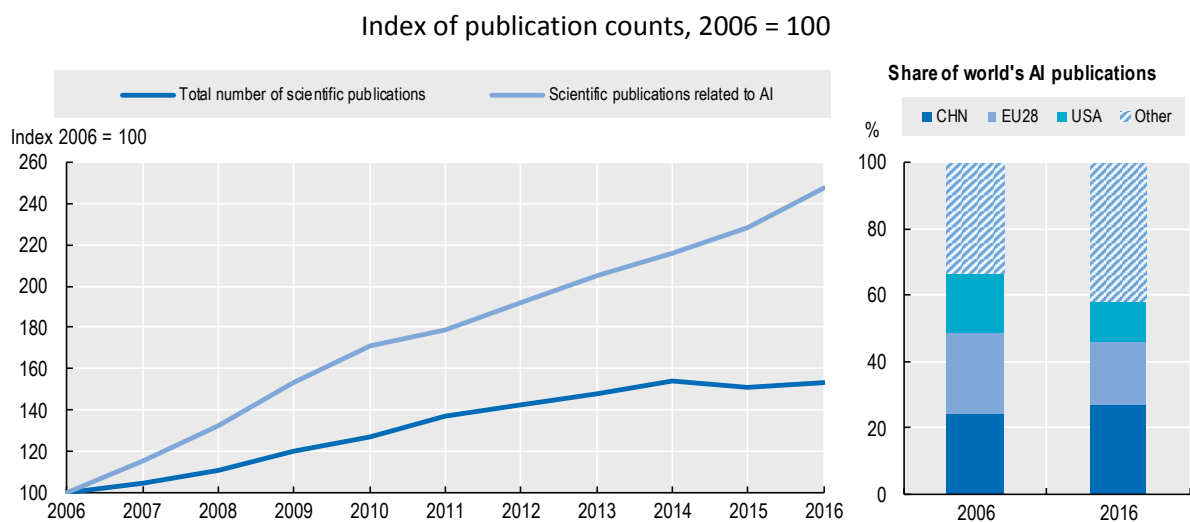
## Support and incentives for digital innovation

Effective policy for innovation in the digital age should include the following objectives (Guellec and Paunov, 2018):

### Data access policies for science and innovation

A key objective of data access policies should be to ensure the broadest possible access to data and knowledge (incentivising sharing and reuse) to favour competition and innovation, while respecting constraints regarding data privacy, ethical considerations, economic costs and benefits (i.e. incentives to produce the data) and intellectual property rights. For example, some governments establish open access to data generated by public services (e.g. urban transportation) to foster data-driven innovation. Conditions should also be created to allow for the emergence of markets for data. Restricting cross-border data flows, or making them more expensive, for instance by obliging companies to process customer data locally, can increase firms' costs and increase the complexity of doing business, especially for small and medium-sized enterprises (SMEs).

**Figure 1.** Trends in scientific publishing related to AI, 2006-16



Sources: OECD (2019a), *Going Digital: Shaping Policies, Improving Lives*, <https://doi.org/10.1787/9789264312012-en>; OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2018 (accessed March 2018) and 2018 Scimago Journal Rank from the Scopus journal title list (accessed January 2019).

### Data and AI in business

Without large volumes of training data many AI models are inaccurate. Governments can take steps to help the development and sharing of training data. Government agencies can help co-ordinate and steward data-sharing agreements between firms, and between firms and public research institutions. In addition, governments can help resolve hardware constraints for young AI firms that need to process vast data streams.

## Providing well-designed support and incentives for innovation and entrepreneurship

Government needs to be flexible and alert to change, as the innovation agenda is shifting quickly. One approach to support policy responsiveness is the deployment and monitoring of small-scale policy experiments, based on which a policy might be scaled up or down. In a context of rapid change, it is also critical to streamline application procedures for innovation support instruments.

Policies should address services innovation. Support for services innovation might include projects to develop entirely new services using digital technologies (e.g. the Smart and Digital Services Initiative in Austria) or support for manufacturing SMEs to develop services related to their products (e.g. service design vouchers for manufacturing SMEs in the Netherlands).

## Cross-cutting policy considerations

### Developing digital skills

Digital technologies create new skills needs. For instance, a general skill shortage exists in AI. But forecasting skills needs is hazardous. Just a few years ago, for example, few foresaw that smartphones would disrupt, and in some cases bring to an end, a wide variety of products and industries.

Governments must establish systems that draw on the collective information and understanding available in businesses, trade unions, educational institutions and learners regarding emerging skills needs. Students, parents and employers must have access to information with which to judge how well educational institutions perform. In turn, educational and training systems must be organised such that resources flow efficiently to courses and institutions that best cater to the demand for skills.

Strong foundational skills are needed throughout the population, such that citizens can more readily acquire specific and fast-changing digital skills throughout life (OECD, 2019a). Another issue is that in many countries – in fields such as AI – male students outnumber female students. Digital technology is also creating opportunities to develop skills in novel ways (Box 2). Curricula may also need to change. In some countries, for example, too few students are trained to understand the fundamental role of logic in AI and data analysis taught to non-specialists in universities is often still based on classical statistics from the early 20th century (OECD, 2018a).

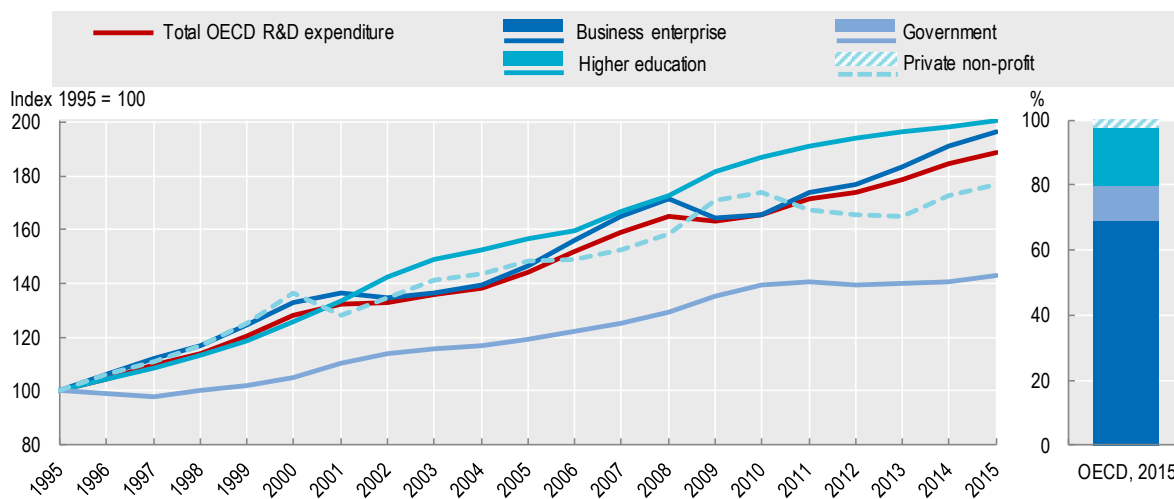
### Ensuring the availability of complementary infrastructures

Broadband networks – especially fibre-optic connectivity – are essential to Industry 4.0. In addition, access to HPC is increasingly important in science, and for firms in industries ranging from construction, to pharmaceuticals and aerospace. How HPC is used in manufacturing is expanding, going beyond applications such as design and simulation to encompass real-time control of complex production processes. As Industry 4.0 becomes more widespread, demand for HPC will rise. But like other digital technologies, the use of HPC in manufacturing falls short of potential. A number of possible ways forward exist, such as providing low-cost, or free, limited experimental use of HPC for SMEs, to establishing on-line software libraries/clearing houses to help disseminate innovative HPC software to a wider industrial base.

### Committing to public sector research

The technologies discussed here have arisen because of advances in scientific knowledge and instrumentation. Publically financed basic research has often been critical. For decades, for example, public funding supported progress in AI, including during unproductive periods of research, to the point where AI today attracts huge private investment. In this context, a recent hiatus – and in certain cases decline – in government support for research in some major economies is a concern (Figure 2).

**Figure 2.** R&D expenditures by performing sector, OECD area, 1995-2015  
Constant price index (USD PPP, 1995=100) and (rightmost) share of GERD in 2015



Source: OECD, *Main Science and Technology Indicators* (database), <http://oe.cd/msti> (accessed July 2017).

### Fostering public-private partnerships in key areas of technology development

The complexity of many emerging digitally driven technologies exceeds the research capacities of even the largest individual firms, necessitating a spectrum of public-private research partnerships. For example, sophisticated and expensive tools are required for research in materials science (which relies on computational modelling and enormous databases of material properties). It is almost impossible to gather an all-encompassing materials science research and development (R&D) infrastructure in a single institute. Some public-private collaborations also stand out for their innovative organisational structures.

### Fostering diffusion of digital technologies

Even in the most advanced economies diffusion can be slow or partial. For example, a survey of 4 500 German businesses in 2015 found that only 4% had implemented digitalised and networked production processes or had plans to do so (ZEW-IKT, 2015). Diffusion in SMEs involves particular difficulties, which partly reflects their more limited availability of ICT skills.

Various micro-economic and institutional settings affect diffusion (OECD, 2017b). One set of measures aims to facilitate the testing of new digital technology applications, for instance by creating testbeds, regulatory sandboxes, and state-of-the-art facilities and expertise.

### Developing technology- and sector-specific capabilities in government

Opportunities exist to use digital technologies that are only likely to materialise if governments possess deep understanding of the technologies and the sectors that deploy them. Deep expertise will also help policy makers and institutions to avoid unrealistic expectations about important digital innovations, especially those that are newly emerging from science (such as quantum computing).

When used, regulation also requires deep industry- and technology-specific expertise. The effects of regulation on innovation are complex, of uncertain duration and can be ambiguous *a priori*. These effects are also likely to be highly technology- and industry-specific. Recent calls to regulate AI exemplify the need for a thorough understanding of the technology, such that any prospective regulation does more good than harm. Data access policies may also need framing with sectoral differences in mind, given the diversity of data types in different sectors.

Designing effective support for sectors requires, as a first step, mechanisms to strengthen policy intelligence. These may include roadmaps or sectoral plans for strategic sectors, prepared in collaboration with industry stakeholders and social partners.



## Using and optimising digital systems to strengthen science and innovation policies

Digital science and innovation policy (DSIP) systems involve procedures and infrastructures using digital technologies to help formulate and deliver science and innovation policy. Data is sourced mainly from funding agencies (e.g. databases of grant awards), R&D-performing organisations, proprietary bibliometric and patent databases, and the web.

DSIP systems can help to develop new STI indicators, assess innovation gaps, strengthen technology foresight, and identify leading experts and organisations.

In OECD survey work, DSIP administrators identified data quality, interoperability, sustainable funding and data-protection regulations as the biggest challenges facing their initiatives. Policy makers wishing to promote DSIP face further systemic challenges, including overseeing fragmented DSIP initiatives; ensuring the responsible use of data originally generated for other purposes; and balancing the benefits and risks of private-sector involvement in providing DSIP data and services (OECD, 2018b).

## Further reading

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Digital technologies and large-scale data flows are fundamentally changing how people live and work, interact with one another, participate in the economy, and engage with the government. The OECD's **Going Digital** project examines how government policy can help ensure this digital transformation benefits all by increasing growth and improving well-being. Going Digital Policy Notes provide insights into key trends, opportunities and challenges, and the policy directions needed for making the most of digital transformation.

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