Artificial Intelligence: A Review of the Economic Context and Policy Agenda

Caroline Paunov and Dominique Guellec

1 Introduction

Artificial intelligence (AI) is seen by many observers as a transformative technology for most economic activities and for government operations. It might be a driver of economic growth in the coming decades, contribute to improved well-being and healthcare, but also trigger churning on the labour market and possibly widening income inequalities. AI will also become a main factor of cybersecurity and national defence systems. Hence the interest of all national governments in this technology and the design and deployment of significant policy agendas.

This chapter will review those agendas. The present analysis is based on the view that AI is one component of a broader set of technologies, digital technologies. Various definitions of AI are offered in the literature, including in other chapters of this book. We will keep to a very general notion, putting under the label "AI" those technologies that produce information and knowledge from data processing. This definition covers machine learning (ML), but also various statistical techniques of data analytics. Both its content in terms of knowledge (data analytics, neural networks) and the requirements for its development (computer power, data availability) emphasise the embedding of AI in the universe of digital technologies, the impossibility of considering AI in isolation of other digital technologies. As a consequence, the conditions of development of AI and the corresponding policies

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C. Paunov
OECD: Organisation for Economic Co-operation and Development, Paris, France
e-mail: Caroline.paunov@oecd.org

D. Guellec (✉)
OST: Observatoire des Sciences et Techniques, Paris, France

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are closely related to those that apply to other aspects of the digital economy, e.g. in terms of infrastructure, skills or access to data. The connections between AI and competition policy, intellectual property and income distribution are examined in a separate study (Guellec & Paunov, 2018).

Accordingly, this chapter will review both the economic context and the policy agenda for AI in close connection with the broader issues of digitalisation. The policy investigation will notably examine 12 selected national initiatives in the field of AI.

2 Digital Innovation, AI and the Economy

Most innovations today are at least partly enabled by digital technologies or embodied in data and software. Digital technologies are enabling the creation of new digital or digitally enabled products and business models (such as social media networks, online marketplaces, on-demand mobility services) as well as the enhancement of traditional ones, as exemplified by connected cars.

Digital technologies are also enabling innovation in production and distribution processes, allowing, for instance, to automate processes with robots, trace products along value chains, better manage stocks with the use of sensors and the Internet of Things (IoT), and predict the maintenance needs of equipment with big data analytics.

Many new opportunities are also arising for accelerating and improving R&D processes. These include the use of big data analytics and large-scale computerised experiments for research, and virtual simulation and 3D printing for developing, prototyping and testing new products.

Today, the effects of digital technologies are felt in all sectors, changing innovation practices and outcomes not only in "born digital" sectors, but also in traditional ones such as agriculture, transportation and retail—as indeed would be expected of general purpose technologies (GPTs) (see Planes-Satorra & Paunov, 2019). GPTs are defined as technologies that drive innovation across the economy and bring long-term social, economic and productivity benefits, as was the case with the steam engine, electricity, the automobile, the computer and the Internet in the past (David, 1990; Bresnahan & Trajtenberg, 1995). The digital transformation is changing innovation processes and outcomes across all sectors of the economy.

Digital transformation changes innovation because digitalisation significantly reduces the cost of producing and disseminating the sort of knowledge and information—innovation's key ingredients—that can be digitalised. Smart and connected products are very different from the tangible products that characterised the previous industrial era.

Three important changes in innovation dynamics have been witnessed across all sectors. First, data are becoming a key input for innovation. Second, innovation cycles are accelerating, with virtual simulation, 3D printing and other digital technologies providing opportunities for more experimentation and versioning in innovation. Third, innovation is becoming more collaborative, given the growing complexity and interdisciplinary needs of digital innovation. AI is a driver and all these transformations and is also affected by them.

2.1 Data as a Core Input for Innovation

Data are a key driver of innovation. Exponential growth in the generation of data of various types (e.g. personal, business, research) and new possibilities for gathering and exploiting such data have made them core inputs of innovation in all sectors of the economy. The development of IoT contributes to steady increases in data generation, as more devices and activities are connected. The deployment of AI and machine learning further increases the expected value of data.

2.1.1 Enabling New Services and Business Models

Data have allowed the development of completely new services and business models. Smart farming services, peer-to-peer accommodation services (e.g. Airbnb), on-demand mobility services (e.g. Uber), peer-to-peer ride sharing (e.g. BlaBlaCar) and platforms to search, compare and book accommodation and transportation options (e.g. Booking) are examples enabled by the availability, and capacity to exploit, large amounts of real-time data.

2.1.2 Enhancing Customisation

Customer data provide important information regarding consumer preferences and needs, which firms increasingly exploit to customise their products. Retailers are increasingly personalising discounts and advertisements using customer purchasing and browsing data. For instance, Sephora uses data from customers' online shopping histories, by employing beacons in their stores which send smart-phone notifications when customers are near an item they had previously added in a digital shopping cart (Pandolph, 2017).

In the health sector, precision medicine is an emerging approach that aims to tailor treatments to individual patients, taking into account their genomic and other biological characteristics, as well as health status, previously prescribed medications and environmental and lifestyle factors. Such advances are enabled by the exploitation of large amounts of patient data and the use of AI and machine-learning tools.

2.1.3 Optimising Processes

Business data are increasingly used to optimise processes within firms but also within supply chains. Manufacturing sectors exploit abundant real-time shop floor data to identify patterns and relationships among discrete processes in order to optimise them—e.g. in terms of waste reduction, energy savings, increased flexibility and better asset utilisation (OECD, 2018). For example UPS, a multinational logistics company, uses a fleet management system enhanced by data analytics that allows for route optimisation, increasing the efficiency and flexibility of delivery processes and reducing fuel consumption. Data are also used to predict the maintenance needs of production systems, significantly lowering maintenance costs compared with regular maintenance and repair activities. In agriculture, data from a multiplicity of sensors can be used to help farmers optimise the use of water and other inputs to boost yields.

Advanced Enterprise Resource Planning (ERP) systems that apply data analytics to optimise end-to-end supply chain planning—increasing its flexibility and capacity to respond to shifts in demand—are also used to a greater extent by firms (Geissbauer et al., 2017). For instance, Amazon has created algorithms to automatically respond to changes in demands: when the popularity of a product increases, the system automatically feeds information into the supply chain system to optimise the inventory, and introduces changes in pricing to maximise benefits (Reeves & Whitaker, 2018).

Blockchain and other distributed ledger technologies (DLTs)—immutable, encrypted and time-stamped databases in which data are recorded, validated and replicated across a decentralised network of nodes—are expected to offer a range of new opportunities for process innovation in the near future. These databases enable parties that are geographically distant to record, verify and share digital or digitised assets on a peer-to-peer basis with fewer or no intermediaries (Nascimento et al., 2018). For instance, the start-up Provenance uses blockchain along with mobile and smart tags to track physical products and verify their claims (e.g. proof of fair payment, social and environmental sustainability of activities) from the origin to the point of sale (Provenance, 2018).

2.2 Faster Innovation Cycles

Digital technologies allow accelerating innovation cycles—reducing R&D costs and time-to-market significantly—due to the new opportunities they offer for more experimentation and versioning.

2.2.1 Designing, Prototyping and Testing New Products and Services

New digitally enabled technologies, such as virtual simulation (made possible by visualisation technologies such as virtual reality and augmented reality) and 3D printing, significantly reduce the cost and time devoted to designing, prototyping and testing processes. They allow testing ideas earlier in development and facilitate multiple iterations and adjustments. Engineers and designers across manufacturing industries increasingly use "digital twins" (i.e. a 3D virtual reality version of a production process or a product) to experiment with designs. In the automotive sector, engineers use design simulation tools to optimise the shape and material properties of parts; they can thereby judge their interactions with other parts, the ease of manufacturing and assembly, and their response to crush-test conditions (Schoenberger, 2014). In the construction sector, specialised software allows design components to fulfil specific functions optimising material (Lehne & Preston, 2018).

2.2.2 Experimenting with (Not Fully Finished) Products and Services on the Market

Digital innovations are often launched to the market even when they are not in their fully finished version (i.e. in beta versions), allowing for more experimentation and product fine-tuning based on consumers' feedback and real-world product performance data. For instance, Tesla Motors installed a "public beta" of its AutoPilot software in more than 70,000 vehicles to test its robustness in different traffic scenarios (Lambert, 2016).

Many firms are also adopting a "lean start-up" method, which consists of creating minimum viable products (MVP) that can be brought to the market. Once launched, producers collect feedback from users and integrate it into their next development round. For example, GE Appliances' FastWorks system, based on lean innovation principles, involves consumers early in the development of new products such as refrigerators (General Electric, 2017).

One factor that could, however, hold back immediate testing with customers is any impact on brand reputation that may come from launching an incremental innovation that is defective or simply judged to be of less value by customers.

2.2.3 Regular Upgrading and Versioning

Many products with digital components allow for regular upgrades, so innovation often does not require releasing an entirely new product but simply consists of an "add on" to products already in the market. Tesla Motors' cars, for example, can receive software updates "over the air", similarly to iOS updates in iPhones. This cumulative nature of upgrades reduces the "cannibalisation" of products (i.e. the creative destruction of its own product by a company): new digital products will not replace existing products of firms, but instead reinforce them.

Such upgrades are however only applicable to the digital components of products. Sectors such as automotive manufacturing, where an important part of innovation is still connected to physical components, have the challenge of devising innovation strategies that consider the co-existence of parallel innovation cycles that run at different speeds. Furthermore, acceleration in versioning and innovation is not synonymous with more rapid technological progress or productivity; many of these frequent improvements are small.

2.2.4 Personalisation

Digital technologies also increase the flexibility of manufacturing, enabling small series production at low cost (similar to the cost of mass production) and thus higher personalisation of products to respond to customers' specific requirements and niche markets. Production responds to orders, which automatically pass through the production planning process to the machine control; the machine then reconfigures itself to process the individual orders. 3D printing can represent a significant enabler technology within this context. Smart products can also be personalised through software rather than hardware, e.g. pay-per-function (Wagner, 2018; Stolwijk & Punter, 2018).

2.3 Collaborative Innovation

Innovation ecosystems are becoming more and more open and diverse. Firms increasingly interact with research institutions and firms, for three reasons. First, this allows them to gain access and exposure to a richer pool of expertise and skills that are complementary to their own competencies (e.g. data analytics). Access to talent is expected to spur creativity and enable innovation in new areas (e.g. integration of data in innovation activities and the servitisation of manufacturing described above). Second, such collaborations allow sharing the costs and risks of uncertain investments in digital innovation. Firms often face several potential research and technology development paths, the mastery of any of which requires large-scale investments with uncertain outcomes. Engaging with others is a way to expand into different areas while collectively sharing costs. Third, reduced costs of communication allow greater interaction among actors engaged in innovation (e.g. firms, public research institutions), regardless of their location.

Collaborations take different forms: (1) data sharing; (2) business incubation; (3) open innovation among actors (e.g. partnerships between firms and digital start-ups, universities); (4) platforms and other innovation ecosystems; and (5) corporate venture capital investments and acquisitions. In this context, new schemes are also set to encourage in-house collaborations.

2.3.1 Data Sharing

The non-rivalrous nature of data allows the same database to be used simultaneously by various actors from different organisations, even if they are located in different places around the world. This has stimulated firms to share their data for research and innovation purposes, often with universities and research organisations or trusted business partners. An example is sharing data with supply chain partners to optimise processes. In the field of retail, for instance, the Kellogg Company's analysed point-of-sale (POS) data from Tesco Supermarkets allows it to identify purchasing patterns and adjust its shipping schedules; it can thereby recover the cost of lost sales and increase consumers' satisfaction (Harper et al., 2009).

Firms are also increasingly making data they are not currently exploiting available to the wider public—for example, with application programming interfaces (APIs), streams of data are made available for developers to create new business opportunities and applications, or to improve existing products. Challenges and hackathons are other popular tools for sourcing external ideas to foster data-driven innovation. Hackathon competitions are 24- to 48-h events in which participants are provided with data with which they have to create an innovative product, often an app. Winners are typically compensated with incubating opportunities (Grijpink et al., 2015).

2.4 Specific Features of AI Within the Field of Digital Technologies

AI has been developing since the 1950s, but it suddenly accelerated in the early 2010s, and it has then generated enormous enthusiasm among researchers, industrialists, observers and policy makers. It has also established itself as a GPT (Brynjolfsson et al., 2019). AI fulfils the definitional conditions of a GPT:

– AI is progressing very fast: all sorts of technical benchmarks have been overtaken by AI over the past years, in all fields: image processing, natural language processing (NLP), machine learning, etc. There have been several successive breakthroughs in all these fields over the years, feeding in progress in performance. In NLP for instance, text embeddings were introduced in 2013, then attention-based transformers in 2017, all giving rise to numbers of derived, applicative inventions. Thanks to this fast progression, AI has the capacity to transform activities where it is used.
– AI is pervasive, it diffuses to all sorts of industrial activities: it is used in industrial processes, inventory management, health monitoring, autonomous driving, consumer relationship management, etc. Information is like energy, a universal input to all production processes, and AI is a way to optimise it in most conditions. AI started as a niche technology, applied to very specific engineering tasks and (although with limited effectiveness) to translation. The diversification of

applications has come with improvements in the core techniques (notably neural networks with more layers and more complex structure) and with the availability of more diverse data, thanks notably to the Internet). Thanks to this pervasiveness, AI is or will soon be used in most industries.

In addition, AI can be seen as a "research technology" (Cockburn et al., 2018), a characteristic that reinforces its potential impact on society and the economy. AI is used in more and more research fields, from astronomy to physics, biology or genetics, history or linguistics. It allows to make sense of large corpora of data, to simulate highly complex models, etc. AI has also gained a central role in more applied fields like synthesis chemistry and drug discovery, as it allows to pre-test enormous numbers of combinations, then selecting the best ones for actual laboratory experiments.

As a GPT and a research technology, AI is considered by many observers as a major source of tomorrow's economic growth, competitive advantage and national capacity. It is therefore quite natural that government would take strong interest in AI and develop policies to encourage its development.

3 Government Policies for Digitalisation and AI

This section, which builds on Paunov et al. (2019), describes and extracts lessons from 12 policy initiatives (4 artificial intelligence strategies and 8 policy programmes) from Australia, Austria, Canada, Denmark, Germany, Ireland, the United Kingdom, the Netherlands, Sweden and the European Union that support digital and data-driven innovation (Table 1).

No specific policy measure from China is presented in this section. This is due to information availability rather than lack of such policies. In fact China has made AI a top policy priority. It started in 2017 with the "New AI Development Plan", that aimed at making China the top global player in AI by 2030. This plan came with various measures, including significant public spending on research, and the setting up of "industry parks" in at least 20 cities. The priority was reinforced in 2021, with the 14th five-year plan, which put innovation top of the agenda for the economic development of China in 2021–2025, and put AI top of the innovation agenda (along with complementary topics like quantum computing or virtual reality), with measures ranging from funding research to sponsoring education. In this context, the Chinese industry is very active: In addition to large investment by companies like Baidu or Tencent, there is a vibrant Venture Capital community in China, which benefits from active support by the government.

The 12 initiatives covered in this section primarily aim to enhance research and innovation in digital fields, including artificial intelligence (AI), the Internet of Things (IoT), augmented reality and blockchain technologies. They intend not only to generate more breakthrough innovations, but also to develop new applications for industry. These initiatives also have a strong collaborative component: they

Table 1 Selected case studies, by country and type of policy initiatives

	Country	Type	Period	Description
Digital innovation policy programmes				
Data61, CSIRO	Australia	Research and innovation centre	2016–present	CSIRO's Data61 is a research and development (R&D) organisation that conducts fundamental and applied research promoting data-driven innovation. It collaborates with other actors in Australia's innovation ecosystem.
Plattform Industrie 4.0	Austria	Policy co-ordination hub	2015–present	Plattform Industrie 4.0, a not-for-profit association, acts as a supportive policy co-ordination hub facilitating the process of digital transformation of industry in Austria by strengthening co-operation and dialogue among all stakeholders.
MADE Digital	Denmark	Collaborative research programme	2017–2020	MADE Digital is a research and innovation programme promoting co-operation between large companies and small and medium-sized enterprises (SMEs), university research teams, and research and technology organisations to jointly develop and implement digital tailor-made solutions that address the specific needs of Danish manufacturing companies.
The Digital Hub Initiative	Germany	Support for digital entrepreneurship	2017–present	The Digital Hub Initiative promotes digital innovation in Germany by attracting digital start-ups to 12 cities specialising in different sectors or technologies, converting them in highly entrepreneurial innovation hotspots.
National Digital Research Centre (NDRC)	Ireland	Support for digital entrepreneurship	2007–present	NDRC is a publicly funded early investor in digital technology companies. It uses an accelerator model that provides them with a wide range of support services, and a modest amount of capital that enables them to become more efficient and investor ready.
Smart Industry Field Labs	The Netherlands	Research and innovation centres	2014–present	Smart Industry field labs are public-private partnerships aiming to develop, test and implement smart-industry solutions in the Netherlands.
AI Innovation of Sweden	Sweden		2019–2021	AI Innovation of Sweden is a national centre for AI-related

(continued)

Table 1 (continued)

	Country	Type	Period	Description
		Research and innovation centre		research, innovation and education. It aims to enhance research and adoption of AI.
Digital Catapult	United Kingdom	Research and innovation centre	2013–present	Digital Catapult is a technology innovation centre driving the early adoption of advanced digital technologies.
AI strategies				
Pan-Canadian AI Strategy	Canada	AI research	2017–present	The Canadian strategy aims to enhance breakthrough research and innovation in the field of AI, notably by supporting a network of AI research excellence centres, and attracting and retaining AI talent.
EU Strategy for AI	European Union	AI research and diffusion across the economy	2019–2027	The EU Strategy for AI aims to promote excellence in AI research, leading not only to breakthrough innovations, but also to the diffusion of AI applications
German AI Strategy	Germany	AI research and diffusion across the economy	2018–present	This strategy aims to make Germany a leading centre for AI by strengthening AI research and talent, supporting the development and adoption of AI by businesses, and taking actions to ensure AI has positive impacts on society.
AI Sector Deal	United Kingdom	AI research and diffusion across the economy	2017–2028	The AI Sector Deal sets a wide range of actions to be undertaken by government as well as industry to maximise the potential of AI in the United Kingdom.

have involved multiple stakeholders from inception to implementation, and are mostly financed by both public and private funding. They focus on challenges similar to those addressed by the "research valorisation" and "industry modernisation" programmes under the French Investments for the Future Programme (*Programme d'investissements d'avenir* [PIA]). This study excludes initiatives that support the deployment of existing digital technologies.

The eight digital innovation programmes can be distinguished as follows. Four programmes are collaborative and multidisciplinary research and innovation centres for digital and data-driven research and co-creation: Data61 of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia, Smart Industry field labs in the Netherlands, AI Innovation in Sweden and Digital Catapult in the United Kingdom. Two programmes support digital entrepreneurship: the Digital Hub Initiative in Germany and the National Digital Research Centre (NDRC) in

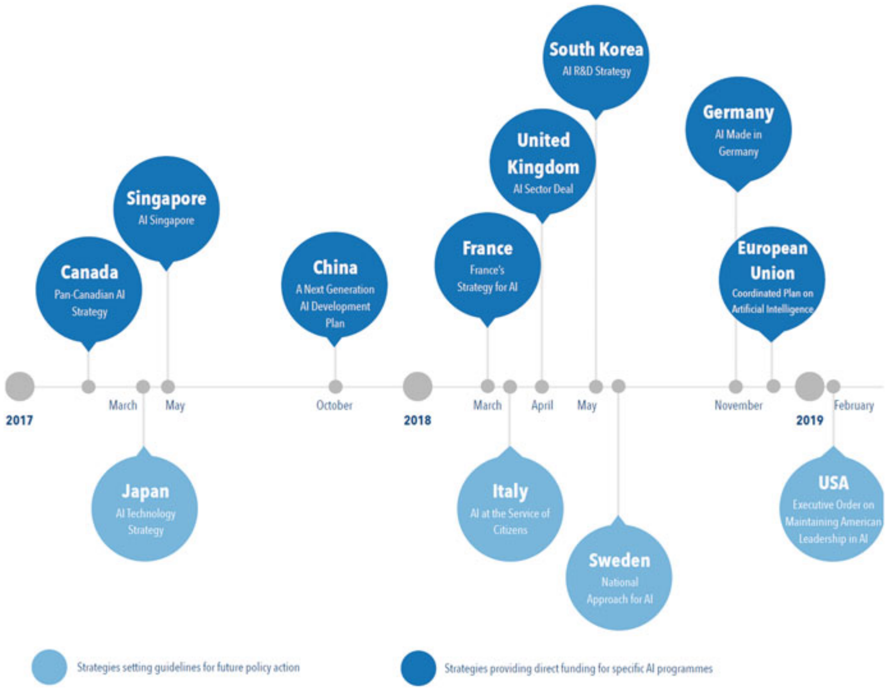

Fig. 1 Timeline of national adoption of AI strategies. *Source*: Planes-Satorra & Paunov (2019)

Ireland. The seventh programme, Manufacturing Academy of Denmark (MADE) Digital, supports smart-industry research projects conducted jointly between firms, universities, and research and technology organisations (RTOs). The final programme, Plattform Industrie 4.0 in Austria, acts as a supportive policy co-ordination hub, facilitating dialogue among all stakeholders on the digital transformation of the country's industry.

The four AI strategies aim to enhance national AI capacities, boosting economic and social benefits from the diffusion of AI, and preventing possible risks associated with the application of AI. The selected cases studied here are the Pan-Canadian AI Strategy (Canada), the EU Strategy for Artificial Intelligence,[1] the German AI Strategy and the AI Sector Deal (United Kingdom). The strategies exemplify the widespread adoption of AI strategies across the OECD (see Fig. 1), adopting different but related approaches. While the Canadian strategy focuses mainly on strengthening capabilities for AI research, the AI Sector Deal in the United Kingdom, developed jointly with industry, is unique in that it incorporates both

[1] The EU Strategy for AI discussed here includes the Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions on Artificial Intelligence for Europe (released in March 2018), and the associated Coordinated Plan on AI.

government and industry commitments. Meanwhile, the EU and German strategies cover a wide variety of AI-related policy domains.

Through the selected programmes, this document highlights trends in how innovation policy initiatives address digital transformation objectives. It presents the rationales for these initiatives and the instruments used, the targeted sectors and technologies, the monitoring and evaluation procedures and the main critical dimensions.

3.1 Digital Innovation Policy Programmes

This section presents the main characteristics of eight digital innovation policy programmes mentioned above. It identifies common trends and highlights their most innovative aspects.

3.1.1 Target Groups

Six of the eight programmes have broad coverage, targeting private companies (including start-ups, SMEs and large companies), the public sector, universities and research institutes. Two of them (MADE Digital in Denmark and the Smart Industry Field Labs in the Netherlands) target research co-operation among different actors.

The two remaining programmes (NDRC in Ireland and the Digital Hub Initiative in Germany) specifically target technology start-ups, investors, SMEs and other firms.

3.1.2 Priority Technologies and Industries

The policy programmes focus on a diverse set of emerging technologies that are especially important to the respective national economies, and thus directly or indirectly target specific industries. For example, the Dutch Smart Industry Field Labs and the Danish MADE Digital initiative focus on Industry 4.0 technologies (e.g. IoT, robotics, 3D printing, digital visualisation) that are particularly relevant to domestic manufacturing firms. The German Digital Hub Initiative also focuses on technologies and sectors reflecting regional strengths (e.g. health, logistics, finance, insurance). In the United Kingdom, Digital Catapult focuses on emerging technologies (e.g. AI, robotics, future networks and augmented reality) to answer the needs of creative industries—one of the country's fastest-growing sectors, accounting for an important share of total employment and service exports. In Australia, CSIRO's Data61 does not specifically target any sector, but its engagement in collaborative or industry-contracted research ensures the relevance of its research to industry.

Practically all of the initiatives target and implement different approaches to supporting breakthrough research and innovation. The Digital Hub Initiative in Germany aims to recreate highly entrepreneurial ecosystems (such as Silicon Valley) in specific locations. AI Innovation of Sweden aims to develop methods and infrastructures to gather large quantities of data (including those donated, acquired and developed internally) to become an international hub for AI research and innovation. Digital Catapult in the United Kingdom provides start-ups with access to key infrastructure (e.g. augmented-reality labs, high-capacity computing) and expertise to facilitate the development of new advanced digital solutions. Finally, CSIRO's Data61 in Australia encourages researchers to undertake risky research with more disruptive potential.

3.1.3 Main Instruments

The programmes use—and often combine—diverse innovative policy instruments. Those identified can be divided into three groups:

1. Policy instruments to support digital technology adoption and diffusion:

- *Testing facilities:* Digital Catapult in the United Kingdom provides several infrastructures to enable prototyping and demonstrating new technologies (e.g. the Dimension Studio facilitates firms' access to immersive production facilities for virtual and augmented reality software [including games], and the Things Connected project allows experimenting with and prototyping new IoT products and services). Most Smart Industry field labs in the Netherlands also provide such spaces. For instance, the Campione field lab provides a facility where innovators in chemical and process industry can experiment with predictive maintenance systems, based on advanced sensors and data analytics.
- *Business advisory services:* The Austrian Maturity Model, developed by Plattform Industrie 4.0 together with Business Upper Austria and the University of Applied Science Upper Austria, offers an independent evaluation of firms' digital readiness through a technology-neutral assessment. With the Inventorium toolkit, NDRC in Ireland provides start-ups with methods and processes for building collaborations and business propositions.

2. Instruments to Facilitate Co-operation and Open Digital Innovation:

- *Collaborative innovation labs:* Smart Industry field labs in the Netherlands, MADE Digital in Denmark and AI Innovation in Sweden all provide physical and digital spaces where science and industry researchers can co-operate and co-create. The services provided include access to prototyping and testing facilities, meeting spaces for researchers, and infrastructures to share and exploit large amounts of data.
- *Open innovation tools:* CSIRO's Data61 in Australia created the Expert Connect Database, containing the profiles of 45,000 research and engineering experts from Australian research organisations, to facilitate co-operation between industry and

researchers. The organisation also created the National Map, a visualisation and access tool for open government data that gathers spatial data from different Australian government agencies in an easily searchable database, to be used in research projects.

- *Matchmaking and networking events:* Several programmes focus on bringing together different actors of the digital innovation ecosystem. The goal is to promote research co-operation, facilitate funding for digital technology research ideas by matching funding institutions to new digital ventures and drive the commercialisation of digital innovations. Digital Catapult in the United Kingdom organises pit-stop events, where start-ups pitch their business proposals to potential partners, clients and investors. In Ireland, NDRC organises "Open Night" networking events for start-ups and potential investors.

3. Instruments to Support Digital Entrepreneurship:

- *Accelerator programmes for early-stage businesses:* the LaunchPad accelerator of NDRC in Ireland offers digital entrepreneurs a 12-week training and mentoring programme. In Germany, several hubs within the Digital Hub Initiative provide trainings and expertise to start-ups: in Munich, for example, the InsurTech Hub's 2-month W1 Forward InsurTech Accelerator Programme targets early-stage start-ups wanting to make an impact on the insurance business with their digital solutions. It provides them with workshops, mentoring and coaching sessions to help them become experts in insurance who are ready to build pilots with corporate members.
- *Access to expertise and advanced infrastructures for start-ups:* in the United Kingdom, Digital Catapult's Machine Intelligence Garage helps early-stage AI companies access computational power and expertise so that they can develop new machine-learning and AI solutions. Digital Catapult's 12-week Augmentator programme supports early-stage businesses in developing innovative and commercially focused applications of augmented reality. In Ireland, the NDRC Catalyser programme provides access to technological expertise for start-ups with a business idea targeting an unmet market need. Start-ups engaging in those trainings are often offered customised mentoring by experts.

Finally, instruments supporting policy making in the digital age include *evidence-based analyses and strategies*. In Australia, CSIRO's Data61 developed several analytical reports aimed at business and government decision makers, including *Distributed Ledgers: Scenarios for the Australian economy over the coming decades*, and *Risks and opportunities for systems using blockchain and smart contracts*. In Austria, Plattform Industrie 4.0 published *Qualification and Competences for Industry 4.0*. This strategy paper compiles 81 recommendations in seven fields of action at five levels (general recommendations, school, initial vocational training, tertiary education and continuous training), building on the available evidence on drivers of—and barriers to—the digital transformation.

3.1.4 Monitoring and Evaluation

Monitoring and evaluation of programmes have generally been conducted by external institutions, but also sometimes by the programmes themselves. Data61 (CSIRO) conducts its own Impact Framework, which requires each team to identify the world-leading groups in its domain, and compare realistically their methods, outcomes and strategy with its own. NDRC publishes an annual report on its activities and achievements, particularly the number of start-ups in which it invested and the resulting job creation. In 2017, NDRC estimated that 29% of companies in which it invested had women in their founding team and found that such start-ups were more likely to secure follow-on investments. The Smart Industry field labs have also monitored their performance by using indicators to track their achievements, particularly the number of projects conducted, the number of university students and PhDs engaged in each lab, and the number of indirect jobs and spinoffs created. In 2016–2018, each field lab engaged on average in eight projects, five field labs generated an average of 79 indirect jobs, and five field labs created spinoffs. Plattform Industrie 4.0, the Digital Hub Initiative and MADE Digital have not yet evaluated their impact.

3.1.5 Critical Dimensions

The critical dimensions of these projects include:

- *Interdisciplinarity and co-operation among different institutions* (notably research and industry) are highlighted in several initiatives. Australia's Data61 comprises research groups that combine expertise in data analytics with specific domain expertise. The UK Digital Catapult is organised around multi-functional teams of technologists; business specialists; product managers; and policy, research and innovation experts. The Dutch Smart Industry field labs support interdisciplinary research and co-operation with a range of partners from industry, research, civil society and government. Finally, the German Digital Hub Initiative emphasises the exchange of cross-sectoral expertise among different hubs across the country.
- *Innovative and less hierarchical organisational structures* have also been adopted to spur creativity and attract talent in digital research and innovation centres. CSIRO's Data61, for instance, has adopted a "start-up" culture with flatter organisational structures, less middle management and more autonomous staff. Research leaders are also encouraged to take risks and experiment with new ideas. Smart Industry field labs also have decentralised structures and work along a project-based approach.
- *Mixed funding models that balance funding from public and private sources* is a key dimension of many of these initiatives. In the case of research centres, such approaches allow them to connect directly with industry needs and demands, while maintaining opportunities to focus on strategic areas of research and action

from a wider societal perspective. Industry funding also allows projects to reach a larger scale and to potentially initiate projects that industry will steer in the future when public funding is applied elsewhere.

3.2 Artificial Intelligence Strategies

New policy strategies (i.e. strategies or plans setting the vision, priorities and general guidelines for policy action) have been developed around the world to respond to the new challenges of the digital age. Many countries have launched national major AI strategies starting in the 2017–2019 period, spurred by the possibly far-reaching implications of AI for the economy and society. The AI strategies often complement their main science, technology and innovation strategy, but are also used alongside other digital or technology-specific strategies (e.g. Germany is preparing its blockchain strategy) (Fig. 1).

This section describes the main objectives and characteristics of four selected AI strategies: the Pan-Canadian AI Strategy, the EU Strategy for AI, the German AI Strategy and the AI Sector Deal (United Kingdom).

3.2.1 Main Objectives

AI strategies differ in terms of their stated objectives and the relative weight given to each objective (Dutton et al., 2018; Planes-Satorra & Paunov, 2019). The common objectives across most AI strategies are as follows:

- *Strengthen research in AI*. This can be done by creating new research centres or devoting specific funding to AI research programmes. The AI strategies of Canada and Germany particularly emphasise becoming international leaders in AI research. The Pan-Canadian AI Strategy, for example, commits funding to three centres of excellence in AI research and innovation (located in Edmonton, Montreal and Toronto) in order to build a leading AI research network.
- *Strengthen AI capabilities*. All strategies emphasise the relevance of attracting, retaining and training domestic and international AI talent, e.g. by creating master's or PhD programmes in AI. The AI Sector Deal in the United Kingdom supports AI fellowship programmes, government-funded PhDs and industry-funded master's degrees. It aims to build 200 new doctoral studentships every year in AI and related disciplines by 2020, and to have at least 1000 government-supported PhD places by 2025. It also aims to grant 2000 "exceptional talent" visas every year to attract international talent, including AI specialists. France and Canada have also created AI programmes to attract and retain top researchers, as well as train young researchers.

  Some strategies, such as the German AI strategy and the French Strategy for Artificial Intelligence, also address the need to help individuals develop new skills for the digital age. For example, the provision of vocational or retraining programmes (e.g. to facilitate human-machine interactions) aims to improve future working conditions in the context of increased automation.

- *Support businesses in developing and adopting AI applications*. This is done, for instance, by providing specific funding for AI start-ups and SMEs. The AI Sector Deal in the United Kingdom has adopted measures to diffuse AI, e.g. by investing in high-potential AI businesses through the Industrial Strategy Challenge Fund competition and the British Business Bank's venture capital programmes. The EU Strategy for AI aims to establish testing facilities to allow experimenting state-of-the-art technologies in real-world environments. It also aims to create Digital Innovation Hubs (DIHs) across Europe to spur the private and public sectors to adopt AI. In particular, these hubs would help companies (including SMEs) identify necessary data sets, develop algorithms and train professionals to use AI solutions.
- *Develop standards for the ethical use of AI.* A common approach is to create expert councils or committees, and fund projects that ensure the ethical and transparent development of AI. The French Strategy for AI develops an ethical framework through a group of international independent experts, following the model of the Intergovernmental Panel on Climate Change. The German AI Strategy establishes an AI Observatory to ensure sustainable development of AI, and to initiate European and transatlantic dialogue on human-centred use of AI in the world of work. The Pan-Canadian AI Strategy funds "AI & Society Workshops", convening international experts to explore the ethical, economic, societal and legal implications of AI.

Less common objectives discussed in AI strategies include:

- *Support investments in infrastructure for AI.* Some strategies highlight the need to invest in specific infrastructure for AI, such as research centres (e.g. the Canadian strategy), AI testing and experimentation infrastructures, as well as telecommunications infrastructure (5G mobile networks, fibre broadband). The EU strategy also stresses the need to invest in high-performance computing, quantum technologies and the cloud.
- *Support responsible data access and sharing*. The AI strategies of France, the European Union and the United Kingdom introduce policy actions pertaining to data access, including incentives for opening data, privacy protection and cybersecurity. The UK AI Sector Deal aims to establish fair, equitable and secure data-sharing frameworks, such as data trusts—mechanisms where parties have defined rights and responsibilities regarding shared data. The strategy also establishes the creation of a Centre for Data Ethics and Innovation, an advisory body that will identify the necessary measures to strengthen and improve the use of data and AI. The French Strategy for AI takes a similar approach: it promotes the creation of sector-specific platforms to compile and share data, provide access to large-scale computing infrastructures suitable for AI and facilitate experimentation in controlled environments.

- *Support AI to achieve inclusiveness and sustainable development.* France, Germany and the United Kingdom incorporate specific inclusion objectives in their AI strategies to ensure a diverse AI talent pool, particularly by encouraging the participation of women and minority groups, and promoting the use of AI applications to drive social inclusion. German AI Strategy supports broad societal dialogue around AI issues and provides funding to develop innovative AI applications that support social inclusion and cultural participation, and benefit the environment. Similarly, the French Strategy for AI supports AI-based social innovations and the creation of a research centre focusing on AI to further the ecological transition.
- *Enhance governments' AI expertise and use.* The German strategy recognises the need to bolster the public administration's expertise in AI. The United Kingdom's AI Sector Deal commits to creating a GovTech Fund, which will support tech businesses in providing the government with innovative solutions to deliver more efficient public services.

3.2.2 Target Stakeholders

The United Kingdom's AI Sector Deal, the German AI Strategy and the EU Strategy for AI target industries target public research institutions and governments. The Pan-Canadian AI Strategy also targets universities and public research institutions, although it additionally aims to promote co-operation between AI research centres and businesses.

3.2.3 Main Instruments

Table 2 presents an overview of the planned actions outlined in the four AI strategies explored above.

3.2.4 Critical Dimensions

- Most AI strategies focus on strengthening research in AI, and building and attracting AI talent. Both of these aspects are seen as necessary conditions to ensure future competitiveness in the field of AI. The strategies focus less on measures to support business adoption and development of AI.
- Some strategies mention the need to invest in specific infrastructures, develop responsible data-access and sharing regulations, enhance government use of AI, develop standards for the ethical use of AI and ensure that AI creates positive impacts on inclusiveness and sustainable development. However, the actions to implement these objectives are often less concrete.

Table 2 Overview of instruments set in AI strategies, by objective

Objective	Main instruments
Strengthen research in AI	– Create three AI research centres of excellence (Edmonton, Montreal, Toronto) and promote their co-operation (Pan-Canadian AI Strategy) – Further develop centres of excellence for AI research (German AI Strategy) – Strengthen Franco-German research co-operation (German AI Strategy) – Review research-funding schemes (German AI Strategy) – Invest in AI under the Horizon 2020 research and innovation programme (EU Strategy for AI) – Create a network of European AI research excellence centres to support collaborative research (EU Strategy for AI) – Increase Engineering and Physical Sciences Research Council (EPSRC) funding for data science and AI research (grants, funding for Alan Turing Institute) (AI Sector Deal, UK)
Strengthen AI capabilities	– AI Chairs programme to attract and retain top researchers, and train young researchers (Pan-Canadian AI Strategy) – Strengthen industry-oriented PhD programmes in AI (EU Strategy for AI) – Create 100 additional professorships for AI (German AI Strategy) – Increase attractiveness of careers in public research (German AI Strategy) – Grant special visas for exceptional AI talent (AI Sector Deal, UK – Create 200 additional AI doctoral studentships (AI Sector Deal, UK)
Support businesses develop and adopt AI applications	– Promote co-operation between AI research centres and business (Pan-Canadian AI Strategy) – Establish testing facilities to facilitate experimentation with AI technologies in real-world environments (EU Strategy for AI) – Establish regional AI clusters that promote science-industry co-operation (German AI Strategy) – Support SME access to AI (e.g. AI trainers in SME 4.0 Excellence Centres) (German AI Strategy) – Establish AI living labs and testbeds (German AI Strategy) – Launch a Tech Growth Fund Initiative (German AI Strategy) – Support application of AI in service sectors (e.g. create "Next-generation services" industrial strategy challenge) (AI Sector Deal, UK) – Integrate AI into future Industrial Strategy Challenge Fund challenges (AI Sector Deal, UK) – Support clusters (e.g. invest in Tech City UK and digital infrastructure) (AI Sector Deal, UK)

(continued)

Table 2 (continued)

Objective	Main instruments
Develop standards for the ethical use of AI	– Fund expert teams to examine social, economic, ethical and legal implications of AI (Pan-Canadian A Strategy) – Preparation of "Ethics guidelines for trustworthy artificial intelligence" by a high-level expert group (EU Strategy for AI) – Creation of an Expert group to the EU Observatory of the Online Platform Economy to explore policy issues in AI-related regulatory areas, such as data access, online advertising and the role of algorithms in the digital platform economy (EU Strategy for AI) – Establish an AI observatory for sustainable AI development (German AI Strategy) – Support Learning Systems Platform to host social dialogue on AI issues (German AI Strategy) – Establish a Centre for Data Ethics and Innovation (AI Sector Deal, UK)
Invest in infrastructures for AI	– Invest in testing and experimentation infrastructures for AI products and services, building on the network of Digital Innovation Hubs (EU Strategy for AI) – Develop super-computing infrastructure (EU Strategy for AI) – Invest in 5G mobile networks and extend full fibre broadband (AI Sector Deal, UK)
Support responsible data access and sharing	– Revise the regulatory framework for the use of data and application of AI (German AI Strategy) – Launch a Support Centre for data sharing (EU Strategy for AI) – Explore new data-sharing frameworks, e.g. data trusts (AI Sector Deal, United Kingdom) – Publish more high quality public data in an open, easily findable and reusable format (AI Sector Deal, UK)
Support AI for inclusiveness and sustainable development	– Fund expert teams to examine social, economic, ethical and legal implications of AI (Pan-Canadian AI Strategy) – Fund AI applications to benefit the environment (German AI Strategy) – Commitment to promote diversity in the AI workforce (AI Sector Deal, UK)
Foster the use of AI by the government	– Recognise the need to develop AI expertise in public administration (German AI Strategy) – Create a GovTech Fund to support innovative tech solutions for more efficient public services (AI Sector Deal, UK)

Source: Based on Planes-Satorra & Paunov (2019)

4 Conclusion

Artificial Intelligence was at the top of the innovation agenda of many governments until the Covid crisis boosted global interest in health-related technologies. It is to be expected that these two technologies will stay together at the top for the foreseeable future. First both of them are subject to intensive demand: the first one for ensuring decent global health conditions; the second one for more competitive reasons—competition between companies, between states. Second, they are complementary in many respects, as AI is increasingly used as a research tool for drug discovery, genetic and other bio analysis, public health monitoring, etc. Third, both are experiencing significant breakthroughs leading to disruptive advances: DNA vaccines have demonstrated that after several decades of disappointing results, biotechnology is now mature enough to produce effective cures; as for AI, it has seen several technological revolutions over the past decade and current basic research is very promising, e.g. for combining machine learning with reasoning abilities (based notably on the cognitive sciences).

AI per se is not only top of the research agenda, it is also influencing other components of the agenda. Research on quantum computing, on cybersecurity, etc. is guided by the willingness to create the best conditions for an efficient use of AI. AI is also needed for progressing research that will allow to fulfil the Sustainable Development Goals: not only on health aspects, but also poverty relief, climate change, or energy optimisation.

The plans reported above demonstrate the interest of government in developing AI, in view of its expected impact on national security, competitiveness and well-being. However, the impact of market forces on the directions of the development of AI should not be underestimated. Research expenditure by businesses clearly dwarfs research expenditure by government. There is no accurate statistics of research expenditure on AI, but indirect evidence points to such dominance of business funding. Whereas most countries' plans include funding ranging from a few million to a few billion USD, spread over several years, the R&D budget of the five top ICT companies in 2019 exceeded USD80 billion: even if not all of it is spent of AI, this is still considerable and beyond the resources of any government. According to data reported by stateof.ai2020, private investment in AI (including Venture Capital) amounted to USD25 billion in 2019. Hence business is the dominant force in financial terms. In addition, as a consequence of strong demand for highly skilled labour in the field, the level of wages commanded by AI scientists has boomed over recent years, with the consequence to crowd out public research and universities (except in the framework of public-private partnership where private funding can flow in). At the Neurips 2019 (the top event in AI research), the top institution in terms of accepted papers, by far, was Google, a company. In 2018 alone, 41 professors left US universities to join companies (stateof.ai2020), a phenomenon that some observers call "the great brain drain". Hence government has limited access to the skills needed to do its own job. It will be a major challenge in the coming years for government to acquire the competences it needs to design and implement an appropriate policy agenda.

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