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Science, technology and innovation in the time of COVID-19

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Abstract

Science, technology and innovation (STI) have played a key role in responding to the COVID-19 pandemic and the unprecedented socio-economic crisis it has triggered. This paper explores how the pandemic affected STI in 2020, including how STI was mobilised to provide vaccines, treatments and innovative (often digital) solutions to address "social distancing". The paper also reviews the quick and agile STI policy responses implemented across countries to stimulate research and innovation activities to find solutions to the pandemic. Moreover, the paper covers STI policies that targeted universities, research centres, innovative businesses and entrepreneurs most affected by the crisis. It also raises key debates on the effectiveness of such policies. Follow-up work will leverage more and better data to improve this early assessment of the impacts of the crisis and STI policy responses.

Keywords: science, technology and innovation (STI); STI policy; COVID-19, OECD countries

JEL codes: O30, I23, D20, H12

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Executive summary

In 2020, science, technology and innovation (STI) was rapidly mobilised to search for a COVID-19 vaccine and treatment, and ways of reducing the costs of "social distancing" measures. Policies to stimulate such efforts and to support STI actors – universities, research centres and innovative businesses and entrepreneurs – most affected by the crisis were implemented at unparalleled speed and scale.

Policy actions and STI activities in response to COVID-19

An impressive battery of policy measures was rapidly adopted to mobilise the STI ecosystem in response to the pandemic. Governments, foundations and industry provided several billion USD for STI geared toward finding COVID-19 solutions. Soon after the beginning of the global COVID-19 crisis in March 2020, countries' policy responses focused on offering fast-track support, soliciting inputs from diverse actors (e.g. through open competitions and hackathons), facilitating research collaboration and knowledge sharing, and easing barriers that could slow down innovation (e.g. through regulatory flexibilities). International actors engaged in co-ordinating R&D efforts and responses, including the World Health Organization (WHO), the Global Research Collaboration for Infectious Disease Preparedness (GLOPID-R), the Coalition for Epidemic Preparedness and Innovation (CEPI), the Gates Foundation, and Wellcome Trust.

The response of the STI ecosystem was similarly impressive, as reflected in the unprecedented speed of vaccine development – a few months compared to an average of 10 years – and the use of new technologies that have never before yielded licensed vaccines. In November 2020, more than 220 vaccine candidates were under development (WHO, 2020[1]). That same month, Pfizer/BioNTech, Moderna and Oxford/AstraZeneca announced that their respective vaccines were more than 90% effective in trials. Already in August 2020, the Ministry of Health of the Russian Federation had approved the Sputnik V vaccine against COVID-19. By the end of December 2020, more than 50 countries had started vaccination campaigns.

Research and innovation efforts were also devoted to developing effective diagnostics and treatments and tackling the socioeconomic challenges posed by the pandemic. As early as April 2020, 200 treatments were being developed, largely outnumbering those taking place in the year following the 2003 SARS and 2014 Ebola outbreaks (Bryan, Lemus and Marshall, 2020[2]). Hundreds of diagnostic tests were also developed (Vandenberg et al., 2020[3]). Scientific efforts are reflected in the surge of COVID-19-related medical research publications. Social scientists, data and machine learning experts also actively engaged in responses to help manage the crisis, including by assessing the socio-economic costs associated with "social distancing" measures and ways of tackling them, combating misinformation, and improving science communication.

Effects of COVID-19 on the STI ecosystem and policy responses

The openness and speed of research on COVID-19 increased compared to prior established practices. Many COVID-19 publications and related research were made publicly available and provided in machine-readable, searchable formats to allow knowledge diffusion at scale. Several initiatives to facilitate research and data sharing (e.g. the CORD-19 initiative created by the Allen Institute for AI, the National Library of Medicine, the Chan-Zuckerberg Initiative, Microsoft, and Georgetown University's Center for Security and Emerging Technology) and access to critical research infrastructures (e.g. high-performance computing) were undertaken to accelerate responses. Many journals accelerated their peer review process to ensure rapid dissemination. Preprints – academic papers that have not yet been peer reviewed – have become more common in the medical field (and beyond) since the start of the pandemic.

Meanwhile, the shock resulting from the COVID-19 lockdown and "social distancing" measures affected the entire STI ecosystem negatively. Immediate effects on research institutions and universities included interrupted research projects due to limited access to research labs; restricted research mobility; diversion of research efforts towards COVID-19 topics; and disruptions in human capital training. Students from disadvantaged backgrounds and early-career and women researchers were particularly affected. Fortunately some of the negative effects were attenuated by the use of digital tools, for instance by quickly shifting to online teaching and virtual conferences. Important policy efforts were devoted to help researchers and research institutions adapt to the new landscape.

Innovative businesses were relatively resilient to the COVID-19 shock in 2020 as a result of the following favourable developments:

- While economic activity contracted significantly in March and April 2020, due to sharp reductions in demand and supply chain disruptions resulting from lockdowns, in most countries activity recovered over the third quarter of 2020. Venture capital (VC) investments also slowed down in the early phase of the COVID-19 shock, affecting in particular early-stage start-ups, but picked up in the second half of the year. Early evidence suggests that trademark applications were unaffected by the crisis, and that patent applications were only moderately affected in the early months of the shock. Yet the latter may be observed in the coming months given the time lag between investments in innovation activities and filing of resulting patents.
- Demand for innovation increased as solutions to the COVID-19 crisis were needed. The demand for innovative digital services to allow "social distancing" (e.g. digital collaboration tools, telemedicine) increased, allowing these sectors to continue investing in innovation to improve their offering. In the USA, business applications increased in the third quarter of 2020, suggesting that the crisis and some of the policy responses may have encouraged entrepreneurship in certain areas where demand increased (e.g. in the digital sector) (US Census Bureau, 2020[4]). Many businesses introduced process and product innovations during 2020 to maintain some of their activities during lockdown or to respond to new market demands. These often implied the uptake of digital technologies.
- The immediate STI policy responses focused on keeping innovative businesses afloat (e.g. facilitating innovative firms and start-ups' access to finance). Large stimulus packages to protect jobs and compensate for income losses due to lockdowns also supported STI actors, including by preventing the market exit of some innovative firms. Those interventions reduced immediate bankruptcy rates substantially with the risk of higher future rates of business closures.

However, this is not to say that business innovation did not suffer. Access to innovation facilities and opportunities for research collaboration were severely hampered, possibly reducing future rates of innovation. A range of low R&D-intensive service sectors (in particular involving tourism, entertainment and necessary in-person interaction) did not see a recovery in demand with implications for opportunities to invest. Small firms were also more affected than their larger counterparts. Differences were also observed across regions, depending on their sectoral composition, the severity of local COVID-19 outbreaks, and subsequent restrictions implemented.

Debates about STI policy actions during the 2020 COVID-19 crisis

The health risk posed by the pandemic and the considerable cost of lockdown policies have exposed to public scrutiny STI policy actions undertaken in 2020. Debates on these immediate responses have focused on the following:

- whether the funding made available to develop solutions was allocated effectively for the best possible STI response;
- whether research efforts were optimally coordinated at national and international levels;
- whether conditions were in place to ensure that vaccines, once available, would be rapidly produced at scale and distributed fairly and efficiently within and across countries; and
- whether scientific advice and communication processes were adequate to manage the COVID-19 pandemic and fit for the future.

Introduction

Coronavirus disease 2019 (COVID-19), first identified in December 2019, became a global health threat by March 2020. In 2020, the pandemic, together with the extensive lockdown measures introduced by most countries in response, resulted in an unprecedented global socio-economic crisis. Meeting the challenge focused on science, technology and innovation (STI) furnishing a vaccine and treatments and reducing costs imposed by "social distancing" measures. Participation in open science and open innovation initiatives also increased sharply. At the same time, global STI activities were severely affected by the pandemic and the ensuing lockdown(s) of the economy. Effects on research institutions and universities included having research projects interrupted due to limited access to research labs; cancelled research mobility programmes; the redirecting of health research to COVID-19 matters; and funding constraints due to expected reductions in income from student tuition fees. Some businesses saw their very survival threatened by a nexus of disrupted research and operations, sharp decreases in demand, liquidity constraints and supply chain disruptions. Many digital service providers' products, by contrast, were given the boost of unprecedented uptake.

This paper looks at the impacts of the COVID-19 crisis on STI ecosystems across countries in 2020. It first explores the STI policy actions immediately undertaken across countries to stimulate STI as a response to the health emergency, and how STI actors rapidly mobilised to engage in these efforts (Section 1). It goes on to analyse the short-term effects of the crisis on different STI actors – universities, public research institutions and innovative businesses and entrepreneurs – and the policies countries have adopted to support their activities (Section 2). The paper then discusses the debates around STI policy actions in response to COVID-19, in particular regarding the efficiency of the global funding allocated to R&D activities during the crisis; the national and international coordination of research efforts; the mechanisms in place to ensure quick and fair access to solutions within and across countries; and the effectiveness of scientific advice and communication processes (Section 3).

The reader is here offered an early overview of developments across countries in 2020. The information provided is based on early evidence and often includes experimental data (i.e. data obtained from non-traditional sources) as more comprehensive information is not (yet) available – thus dates for the information are provided. As to the review of policy initiatives, the report does not provide a comprehensive collection, but rather to illustrate policy trends across OECD countries. Nor is the aim to assess those policy responses. Follow-up work will leverage more and better data to improve the early assessment of the impacts of the crisis and policy responses provided here.

The paper is released jointly with the paper "What future for science, technology and innovation after COVID-19?", which explores the longer-term impacts of the crisis on STI (Paunov and Planes-Satorra, 2021[5]). This paper, jointly with the latter paper, constitutes a background paper to Chapter 1 of the *OECD Science, Technology and Innovation Outlook 2021* (OECD, 2021[6]).

Country policy information was collected through the OECD Survey on STI Policy Responses to COVID-19 ("STIP COVID-19 Watch"), with insights provided by the webinar organised by the OECD New Approaches to Economic Challenges (NAEC) initiative on "Building resilient systems in the 21st century" (23 April 2020); the workshop "STI readiness and response in times of global emergencies" (1 April 2020); and the series of webinars[1] organised by the OECD Committee for Scientific and Technological Policy (CSTP). It also builds on the workshop "Science, technology and innovation in times of COVID-19: What policy responses for the recovery?" (17 and

24 June 2020) and the series of expert webinars[2] organised by the OECD Working Party on Innovation and Technology Policy (TIP). There is additional input from expert interviews and diverse sources of early data (Box 1).

The analysis also draws on previous CSTP and TIP work on the impacts of the 2008-09 crisis on STI systems (OECD, 2012[7]; Guellec and Wunsch-Vincent, 2009[8]) and on expertise in the areas of digital innovation (OECD, 2019[9]; Paunov and Planes-Satorra, 2019[10]; Paunov et al., 2019[11]), science-industry knowledge transfer and co-creation (OECD, 2019[12]), open science (OECD, 2015[13]; Dai, Shin and Smith, 2018[14]) and systems innovation (OECD, 2015[15]).

Box 1. Useful OECD resources related to STI & COVID-19

STI COVID-19 Policy Tracker:

The OECD launched a survey to collect information on the various science and innovation policy measures and arrangements countries use to respond to the COVID-19 crisis. Country responses to the survey are available at a dedicated website, the "STIP COVID-19 Watch" (stip.oecd.org/Covid.html). This new tool allows building timelines of policy initiatives and has interactive dashboards that allow exploring data by countries, themes and target groups. As the situation is fast evolving, countries are submitting information on a rolling basis and the website is updated daily. The OECD Global Science Forum has also collected information on emergency research funding initiatives.

OECD Hub on policy responses to COVID-19:

The OECD is compiling data, analysis and recommendations on a number of topics to address the emerging health, economic and societal crisis, facilitate co-ordination, and contribute to the global action necessary when confronting this enormous collective challenge. The new OECD dedicated page (www.oecd.org/coronavirus/) brings together policy responses covering aspects such as health, education and taxes. The web page provides guidance on the short-term measures needed, with a specific focus on the vulnerable sectors of society and the economy. It also provides analysis of the longer-term impacts of the crisis, paving the way to recovery with co-ordinated policy responses across countries.

Policy briefs related to STI are provided in the OECD Hub. These include "Crowdsourcing STI policy solutions to COVID-19", "Start-ups in the time of COVID-19", "Science, technology and innovation: How co-ordination at home can help the global fight against COVID-19", "Providing science advice to policy makers", "Using AI to help combat COVID-19", "Why open science is critical to combatting COVID-19" and "Ensuring data privacy as we battle COVID-19".

1. Mobilisation of STI efforts to address the COVID-19 health crisis

This section explores the STI policy actions immediately undertaken across countries to stimulate R&D and innovation to address the COVID-19 crisis, and how STI actors rapidly mobilised to engage in these efforts.

1.1. Policy actions to support R&D and innovation in the time of COVID-19

(1) Governance of policy actions to address COVID-19

Jointly with national governments, diverse foundations and international institutions actively engaged in STI policy actions to respond to COVID-19. The latter notably include the World Health Organization (WHO), the Global Research Collaboration for Infectious Disease Preparedness (GloPID-R) and the Coalition for Epidemic Preparedness and Innovation (CEPI) (Table 1). Among the foundations participating are the Bill and Melinda Gates Foundation, Wellcome Trust and the Novo Nordisk Foundation. These globally operating bodies have among their objectives the harnessing of science and innovation to address infectious diseases. In response to the COVID-19 pandemic in 2020, they have not only been providers of funding but also engaged with STI responses to the challenge at the global level, focusing specifically on the difficulties faced by developing countries.

International co-ordination and information-sharing mechanisms were established to co-ordinate global research efforts. Since the start of the crisis, the WHO has worked closely with the GLOPID-R– a network of major research funding organisations, aimed at facilitating rapid responses to infectious disease outbreaks – to identify specific funding priorities (GloPID-R, 2020[16]). On 11-12 February 2020, they jointly organised the Global Forum on Research and Innovation for COVID-19, gathering over 400 participants from across the world (including scientists, member states' representatives, public health professionals, funders and private sector representatives). Based on the forum's discussions the WHO released in April 2020 a "Coordinated global research roadmap for the 2010 novel coronavirus", which set nine research priority areas to address the health pandemic[3] (WHO, 2020[17]). In July 2020, the GloPID-R organised a series of COVID-19 Research Synergies Meetings to identify crucial knowledge gaps for and streamlining research efforts (Boily-Larouche et al., 2020[18]).

CEPI – a global partnership among public, private, philanthropic and civil society organisations created in 2017 to accelerate the development of vaccines against emerging infectious diseases – raised more than USD 1.3 billion (as of October 2020) to develop vaccine candidates against COVID-19, which CEPI invested in collaborations with a number of pharmaceutical firms, universities and research organizations (CEPI, 2020[19]). With the objective of creating a similar initiative to accelerate the development and scaling-up of treatments, in March 2020 the Bill & Melinda Gates Foundation, Wellcome and MasterCard launched the COVID-19 Therapeutics Accelerator, with an initial budget of USD 125 million. By the end of October 2020, the endeavour had awarded USD 98.6 million in grants (COVID-19 Therapeutics Accelerator, 2020[20]).

Table 1. Initiatives supporting international coordinated STI responses to COVID-19

	Overview	Members / Donors	Focus of COVID-19 STI responses	Funding for COVID-19 responses
World Health Organization (WHO)	Established in 1948, it is a specialized agency of the United Nations responsible for international public health. Its objective is the "attainment by all peoples of the highest possible level of health". Its mandate includes coordinating responses to health emergencies.	194 Member States and 2 associate members	Coordination at global scale of the response to the COVID-19 health emergency. In March 2020, the WHO released the "Coordinated global research roadmap for the 2019 novel coronavirus", which specifies 9 research priorities to tackle the COVID-19. The WHO and its partners also launched the "Solidarity" clinical trial to test treatments against COVID-19 with volunteer patients from multiple countries; the "Solidarity Response Fund", a global crowd-funding initiative to support the work of WHO and its partners on COVID-19 (including R&D); the Access to COVID-19 Tools Accelerator, to ensure equitable access to COVID-19 diagnostics, therapeutics and vaccines; and the COVID-19 Technology Access Pool, a voluntary repository to share COVID-19 health technology related knowledge, IP and data.	WHO mobilised USD 236 million under The Solidarity Response Fund (as of 14 October 2020)
Global Research Collaboration for Infectious Disease Preparedness (GloPID-R)	Created in 2013, it is a network of major research funding organisations, aimed at facilitating rapid responses to infectious disease outbreaks.	29 research funding organisations in the area of infectious disease preparedness research	Research response coordination at global level. Since the start of the crisis, GloPID-R has worked closely with the WHO to identify specific funding research priorities to tackle the COVID-19, captured in the "Coordinated global research roadmap for the 2019 novel coronavirus"	GloPID-R does not fund projects directly but coordinates and shares information among the funding organisations
Coalition for Epidemic Preparedness and Innovation (CEPI)	Created in 2017, it is a global partnership between public, private, philanthropic and civil society organisations, aimed at accelerating the development of vaccines against emerging infectious diseases.	Governments of 28 countries; European Commission; Bill & Melinda Gates Foundation; Wellcome	Funder and facilitator of vaccine discovery, development, manufacture and delivery. CEPI has initiated 10 partnerships to develop vaccines against COVID-19: 6 with pharmaceutical firms (Novavax, CureVac, Inovio Pharmaceuticals, Moderna, Clover Biopharmaceuticals, SK Bioscience), 2 with universities (University of Queensland and University of Hong Kong) and 2 with public-private consortia (University of Oxford – AstraZeneca; Institute Pasteur - Themis Bioscience -University of Pittsburgh).	USD 1.3 billion (as of October 2020). In addition to funding from donors, CEPI has received donations from the private sector and individuals through the UN Foundation's COVID-19 Solidarity Response Fund.
Accelerating COVID-19 Therapeutic Interventions and Vaccines (ACTIV) partnership	Created in April 2020, it is a public-private partnership to develop a coordinated research strategy for prioritizing and speeding development of the most promising treatments and vaccines.	8 Government agencies (incl. NIH, BARDA, US FDA, European Medicines Agency), 4 non-profit organisations and 20 pharmaceutical companies.	Coordinate and streamline processes to make the best use of biomedical research resources. It pursues four fast-track focus areas: Develop a collaborative, streamlined forum to identify preclinical treatments; Accelerate clinical testing of the most promising vaccines and treatments; Improve clinical trial capacity and effectiveness; Accelerate the evaluation of vaccine candidates to enable rapid authorization or approval.	The initiative receives funding from its different partners

Source: WHO (2020[17]), GloPID-R (2020[16]), CEPI (2020[19]), NIH (2020[21]).

Other international initiatives bringing together a diversity of stakeholders were also created. On 17 April 2020, the National Institutes of Health (NIH) announced the Accelerating COVID-19 Therapeutic Interventions and Vaccines (ACTIV) partnership, gathering as of December 2020 the world's largest pharmaceutical companies (numbering 20), non-for-profit organisations (including the Bill & Melinda Gates Foundation and the Fred Hutchinson Cancer Research Center), other US Government organisations and the

European Medicines Agency, with the aim of developing an international strategy for a co-ordinated research response to speed vaccine and treatment development (NIH, 2020[22]; Collins and Stoffels, 2020[23]). On 24 April 2020, the WHO launched the Access to COVID-19 Tools (ACT) Accelerator – a global collaboration project joining public health actors, philanthropies, private sector partners and other stakeholders – to ensure equitable access to new COVID-19 diagnostics, therapeutics and vaccines and to strengthen health systems (WHO et al., 2020[24]). On 4 May 2020, the European Union and its partners launched a global pledging effort – the Coronavirus Global Response – to raise EUR 7.5 billion (USD 8 billion) to ensure the collaborative development and universal deployment at an affordable price of diagnostics, treatments and vaccines. As of 8 September 2020, EUR 15.9 billion (USD 18.8 billion) had been pledged, of which EUR 9.5 billion was raised over the month of May (European Union, 2020[25]).

Co-ordination mechanisms have also been set up to ensure efficient STI responses and implementation of measures at the national level (e.g. cross-ministerial strategies and plans) and sub-national levels of government, as regional and local authorities have been at the forefront of immediate responses. Relevant mechanisms already in place have been activated, an example of which is REACTing. This collaborative network of French research institutions working on emerging infectious diseases has played a key role in co-ordination and information sharing regarding COVID-19 research in France. In other cases, new co-ordination mechanisms have been set up: the cross-governmental National Action Plan on COVID-19 in Ireland, the National Command Council and Inter-ministerial Research Committee on COVID-19 in South Africa, and the Quebec COVID Network in that province of Canada. In the United States, the Operation Warp Speed coordinated the US government's investments in R&D, manufacturing, purchasing and distribution of vaccines, diagnostics and therapeutics.

Recognising the global returns to having a vaccine and effective treatments in place, governments, firms and foundations committed large amounts of funding to R&D activities addressing the health emergency. The US National Institutes of Health alone devoted USD 3.6 billion to COVID-19 research (as of January 2021) (NIH, 2021[26]). The European Commission mobilised EUR 1 billion (USD 1.2 billion) for investment by the end of 2020 under Horizon 2020, the EU framework programme for research and innovation. Of that amount, EUR 549 million had been invested by September 2020 in grants for 103 research projects targeting the pandemic (European Union, 2020[27]) (European Commission, 2020[28]). Several R&D funding trackers provide regularly updated estimates of the total amounts of funding allocated to COVID-19 R&D projects. According to the tracker developed by Policy Cures Research, a global health think tank, more than USD 9.1 billion had been committed by government, industry and philanthropic organisations to these projects as of 18 September 2020. Nearly 60% of such funding was allocated to vaccine R&D (Policy Cures Research, 2020[29]). An ad hoc data collection by the OECD Global Science Forum shows that an estimate of total public and philanthropic investments in R&D projects amounted to USD 6.6 billion as of September 2020 (OECD, 2020[30]).

A diversity of approaches has been adopted to allocate this funding. Since the early days of the crisis, many governments *fast-tracked competitive research funding initiatives* (Table 2)*;* the challenge for these accelerated procedures is to ensure fair, competitive and transparent merit review and selection processes. For instance, on 6 March 2020 the French National Agency for Research (ANR) launched a Flash COVID-19 call (EUR 3 million, soon increased to EUR 14.5 million) allowing the evaluation, selection and funding of research proposals within a short period. Other examples are the fast-track research calls launched by the Australian Medical Research Future Fund (USD 10.8 million, March 2020), the UK National Institute for Health Research and the funding agency UK Research and Innovation (GBP 20 million, February 2020), the Innovative Medicines Initiative (EUR 45 million, March 2020) and the Swiss National Science Foundation (March 2020). The US National Science Foundation (NSF) can also fast-track research requiring an urgent response through the Rapid Response Research (RAPID) funding mechanism. Created in 1990 and reformulated in 2009, RAPID is now used to review proposals related to COVID-19.

Table 2. Fast-track R&D funding initiatives for COVID-19-related research of March-April 2020, selected examples

Country	Programme	Funding agency	Focus	Amount of funding	Date launched
Australia	Medical Research Future Fund (3 open competitive grants)	Medical Research Future Fund, Department of Health	Treatments, clinical trials, vaccines	USD 10.8 million (AUD 15 million)	23 and 25 March
Austria	COVID-19 Emergency Call	Federal Ministries for: Digital and Economic Affairs; Climate Action, Environment, Energy, Mobility, Innovation and Technology; Education, Science and Research	Diagnostics, treatments, clinical trials	USD 27 million (EUR 23 million)	9 and 21 March
Canada	Rapid Research Response to COVID-19	Canadian Institutes of Health Research	Medical and social countermeasures	USD 50 million (CAD 54.2 million)	10 February
France	COVID-19 Flash call	National Research Agency (ANR)	Four priorities identified by WHO*	USD 17.2 million (EUR 14.5 million)	6 March
Germany	Research Call for COVID-19 Treatment Options	German Federal Ministry of Education and Research	Treatments, clinical studies	USD 53.5 million (EUR 45 million)	3 March
Japan	Drug Discovery Support Program: Development of COVID-19 vaccine	Japan Agency for Medical Research and Development	Vaccines	USD 97 million (JPY 10 billion)	13 April
New Zealand	COVID-19 New Zealand Rapid Response Research and Emerging Infectious Diseases Grant	Ministry of Health and Health Research Council	Multiple fields	USD 1.8 million (NZD 3 million)	2 March
Spain	Special Spanish Research Programme on COVID-19	Institute of Health Carlos III – Ministry of Science & Innovation	Vaccines, diagnostics, treatments, social impacts, public health	USD 28.2 million (EUR 24 million)	19 March
United Kingdom	COVID-19 Rapid Response Calls	National Institute for Health Research and UKRI	Vaccines, treatments, diagnostics, social science research and other	USD 25.8 million (GBP 20 million)	4 February
United States	Rapid Acceleration of Diagnostics (RADX)	National Institutes of Health (NIH)	Diagnostics	USD 248.7 million (as of 31 July 2020)	29 April

Note: * The French call focuses on the following four priorities: epidemiological and translational studies; the pathophysiology of the disease; infection prevention and control measures in the healthcare setting and in community settings; ethics and the humanities and social sciences associated with the response.
Source: OECD STIP COVID-19 Survey and programme websites.

In some cases, *support was channelled through existing funding mechanisms* to accelerate responses. In March 2020 the European Commission called for start-ups and SMEs with technologies and innovations that could help in treating, testing, monitoring and other aspects of the crisis to apply to the next round of funding from the European Innovation Council, which had a budget of up to EUR 164 million. While there were no predefined thematic priorities, the Commission committed to fast-track EIC grants to COVID-19-relevant innovations. The US NSF also encouraged the research community to respond to the COVID-19 challenge through existing funding opportunities. In Canada, one of the measures of the "Mobilize Industry" plan was the refocusing of existing industrial and innovation programmes (e.g. the Strategic Innovation Fund, Innovation Superclusters) on the fight against the virus.

Some government calls also encouraged existing *grant holders to repurpose their research and innovation* activities. For instance, the UK Research and Innovation (UKRI) grants programme for ideas that address COVID-19 invited researchers holding existing UKRI standard grants to switch that funding to COVID-19 priority areas (UKRI, 2020[31]). It is important however that other measures, such as open competitions, are implemented in parallel to ensure that all capabilities are mobilised, including those of researchers in different disciplinary areas, firms, and non-traditional innovators with new ideas for solutions.

Governments also invested in *improving the visibility of research funding opportunities*, often by creating online platforms that list all relevant information on COVID-19-related STI activities, such as the European Commission's European Research Area (ERA) corona platform and the Portuguese Science 4 COVID-19 portal (OECD, 2020[32]).

(2) Policies for rapid innovation to respond to COVID-19

Most countries also implemented measures to stimulate quick innovative responses to the wide range of challenges posed by the virus – from preventing transmission, to producing essential supplies, combating misinformation, and handling the effects of the lockdown. Approaches include those listed in the following paragraphs.

Fast-track open competitions were launched to stimulate out-of-the-box thinking and gather inputs from all parts of STI systems – from firms to research teams and individual inventors. In some cases the challenge was clearly identified. For instance, the UK launched a call for innovative sanitising technologies allowing ambulances to be cleaned rapidly after a patient with suspected COVID-19 has been transported. In Canada, the COVID-19 Challenge Programme posts specific challenges seeking near-to-market solutions from firms with fewer than 500 employees (e.g. a low-cost sensor system for COVID-19 patient monitoring) (Government of Canada, 2020[33]). In Italy, under the "Innovate for Italy" initiative, a fast call competition was launched to identify best digital solutions available for telemedicine and monitoring applications for patients (MID, 2020[34]). In other cases, such as the COVID-19 Rapid Response Call in Ireland and the fast-track competition for business-led innovation in response to global disruption in the United Kingdom, applicants were asked to demonstrate the relevance of their innovations to the challenge they were addressing.

Virtual hackathons were much used in the early phase of crisis. Organised by governments, non-profits, universities and supranational and international organisations, their objective was to draw ideas from diverse contributors. Hackathons are typically 24- to 48-hour events in which participants are provided with data with which they have to create an innovative product. Winners are often compensated with funding to develop and scale their ideas. For instance, the European Commission organised the "EUvsVirus Hackathon" on 24-26 April 2020 to address around 20 COVID-19-related challenges. A total of 117 innovative solutions (of the more than 2 100 submitted) were selected as winners in different challenge categories, including a highly scalable patient monitoring system that minimises the need for physical contact between nurses and patients (as part of the health category); a remote queuing solution to ensure social distance in retail (business continuity category); and an online village platform for virtual learning (remote working and education category). Other hackathons include the #BuildforCOVID19 (26-30 March 2020) organised by the World Health Organisation with the support of technology firms; Hack the crisis (13-15 March 2020) organised by Accelerate Estonia and Garage48 (an organisation founded by start-up entrepreneurs that has been organising hackathons since 2010) and the series of MIT COVID-19 Challenges organised by the Massachusetts Institute of Technology (MIT) from March to November 2020.

The European ("EUvsVirus") hackathon was followed by an online "Matchathon" in May 2020 to help winning teams match with corporates, investors and accelerators around the world to put their innovative solutions into production. This matching exercise sparked the development of 2 235 partnerships between the 117 winning teams and 458 supporting partners from the private and public sectors (European Commission, 2020[35]). Some solutions were implemented, such as #WeStudyTogether – an online peer-to-peer learning community platform enabling educational institutions and teachers to engage their students remotely, preventing student knowledge gaps and increasing retention.

Collaborations for research and innovation were also promoted. In Canada, the Pandemic Response Challenge Program aimed to mobilise Canadian and international researchers from universities, business and government to work together to address specific COVID-19 challenges identified by Canadian health experts (Government of Canada, 2020[36]). In the Czech Republic, a COVID-19 innovation vouchers call was launched to promote the sharing of knowledge and know-how between businesses and the research community to combat the virus and mitigate its impacts. A similar voucher programme was launched in the Italian region of Piemonte.

A number of calls focused explicitly on *promoting international collaborations.* For instance, in May 2020 the National Research Foundation (NRF) of Korea launched a Rapid Call for International Joint Research against COVID-19, to conduct epidemiological research involving Korean researchers collaborating with researchers abroad. The National Natural Science Foundation of China (NSFC) and the Russian Foundation for Basic Research (RFBR) launched an international call for collaborative COVID-19 research proposals from teams comprising researchers from the People's Republic of China and the Russian Federation. Another example is the Nordic Health Data Research Projects on COVID-19, a call to foster research co-operation and health data sharing across Sweden, Finland, Denmark, Norway, Iceland, Estonia and Latvia. EUREKA, an intergovernmental network for international cooperation in R&D and innovation, launched a call for proposals on "solutions for COVID-19 echo period – life without a vaccine" in April 2020, inviting R&D performers in eight countries (Austria, Canada, Denmark, France, the Netherlands, South Africa, Spain and Turkey) to apply for coordinated funding for research relevant to the prevention, diagnosis, and treatment of COVID-19. A second multilateral call for proposals launched in May 2020, including eleven countries (Belgium, Estonia, Finland and Germany, in addition to the previously mentioned except for Austria), focused on the collaborative development of technologies relevant to highly infectious diseases in general. These initiatives built on the network's prior experience in facilitating international R&D collaborations (331 projects in 2019) to rapidly roll out calls related to COVID-19.

Data and knowledge sharing was also encouraged. The EU and several partners established a COVID-19 data portal to enable rapid and open sharing of research data. In April 2020, the European Data Protection Board (EDPB) adopted guidelines on the processing of health data for research purposes linked to the pandemic, addressing legal questions concerning international data transfers and the implementation of adequate safeguards (EDPB, 2020[37]). National initiatives have also been adopted to encourage knowledge sharing across different actors in the system. In Germany, the Federal Ministry of Education and Research (BMBF) allocated EUR 150 million to establish a National Research Network of University Medicine on COVID-19 – a centralised infrastructure to collect data on the treatment of patients with COVID-19 in a standardised way, and bring together and evaluate action plans and diagnostic and treatment strategies of all German university hospitals.

Regulatory flexibilities were introduced to ensure rapid responses while maintaining safeguards. These drew from existing emergency procedures of regulatory bodies, and were used to accelerate clinical trials to test new treatments and vaccines; the development of new products (e.g. diagnostics tests); and the manufacturing of products to address supply shortages (e.g. of medical equipment, medicines). Such mechanisms need to ensure compliance with ethical and scientific quality standards to safeguard the rights, safety and well-being of trial participants, patients and consumers.

For instance, in Australia, the Therapeutics Goods Administration (TGA) has fast-tracked regulatory assessment of applications for COVID-19-related therapeutic goods. A number of exemptions for complying with normal regulatory processes and approvals were also put in place in that country to facilitate faster access and supply of tests, personal protective equipment and medical devices. In the United States, the Food and Drug Administration allowed the State of New York flexibility in expediting authorisation for certain laboratories to develop and perform diagnostic tests. In the Russian Federation, procedures to register medical devices for the diagnosis of COVID-19 were accelerated. In the United Kingdom, the Medicines and Healthcare Products Regulatory Agency published a package of regulatory flexibilities on 1 April to support the healthcare response to COVID-19, including through rapid reviews of clinical trial applications and expedited clinical investigations of medical devices. The European Medicines Agency provides guidance on clinical trial management during COVID-19.

Initiatives to *facilitate access to research infrastructures*, such as laboratories, databases and tools, were launched to help researchers accelerate their activities. For instance, the public-private COVID-19 High Performance Computing Consortium in the United States provides COVID-19 researchers worldwide with access to high-performance computing (HPC), and the European Research Infrastructure on Highly Pathogenic Agents offers access to in-vitro and in-vivo research capacities to those conducting studies on COVID-19. CeADAR, Ireland's National Centre for Applied Data Analytics and Machine Intelligence, has also offered its artificial intelligence (AI) expertise to help companies, government agencies and medical centres apply AI tools to help track the virus. In September 2020, three MedTech Open Innovation Testbeds (TBMED, MDOT and SAFE-N-MEDTECH) also launched a call open to innovative SMEs, companies, start-ups and applied research institutions working on the development of solutions to fight the pandemic. Selected innovators will be provided with services to help them reach the market faster (MDOT, 2020[38]). The Association of European-Level Research Infrastructures Facilities (ERF-AISBL) (2020[39]) provides an overview of research infrastructures providing open access to their facilities or specific services to support COVID-19 research.

Intellectual property measures were also adopted (WIPO, 2020[40]). In an effort to support COVID-19 solutions, on 8 May 2020, the United States Patent and Trademark Office (USPTO) launched a COVID-19 prioritised examination pilot programme to accelerate the examination of COVID-19-related patent applications submitted by small and micro entities without incurring additional fees (USPTO, 2020[41]). There is an IP-related ongoing debate over harnessing incentives to develop solutions for COVID-19 without restricting the wider global population's access to those solutions, particularly in developing countries. Knowledge Transfer Ireland (KTI) created a COVID-19 Non-Exclusive Royalty-Free (NERF) Licence to speed up dissemination of COVID-19-related IP from Irish universities and institutes of technology to firms engaged in R&D activities aimed at diagnosing, preventing, containing or treating the impacts of the virus. At global level, in May 2020 the WHO launched the COVID-19 Technology Access Pool (C-TAP), a voluntary repository to collect and share patent rights, regulatory test data and other information to ensure access to rights for related medical products.

(3) Innovative policy approaches

New approaches were also implemented to improve the STI policy responses. This included, first, the use of *digital tools to design and implement research and innovation policy*. Such tools helped make decisions quicker and more effective, based on stronger evidence. For instance, the Italian Ministry of Universities and Research launched a mapping activity to collect information about all ongoing and planned research projects on COVID-19, with the objective of reducing fragmentation and preventing unnecessary duplications. The US National Science Foundation developed a visualisation tool that clusters all NSF-funded research projects addressing the pandemic into groups of similar topics, based on the application of machine-learning techniques to abstracts of project proposals. This reduces risks of duplication in grant awards, facilitates the identification of synergies across projects, and makes it easier to have a complete picture of the research areas being funded and their relative importance (Columbia University, 2020[42]).

Second, a range of *approaches were implemented to monitor the impacts of the crisis on different STI actors*. For instance, Israel conducted monthly surveys and organised roundtables with main stakeholders to have a comprehensive picture of the main challenges faced by innovative businesses during the pandemic. Open data sharing through such initiatives as CORD-19 has not only supported scientific activities but also been used by policy to identify the nature of scientific contributions to tackling COVID-19. Early analysis of such data pointed, for instance, to the drop in female research activities and the high reliance on existing networks for research collaborations.

Finally, efforts were also made to *enhance the responsiveness capacity of the public administration to this and future crises*, drawing on existing capacities in the STI system. In Finland, the Fast Expert Teams initiative was set up in March 2020 to help ministries respond to COVID-19 related challenges. The initiative consists of a rapidly growing voluntary *pro bono* online network that gathers experts from universities, private and public sector organisations and ministries to solve complex emerging problems requiring specialised and complementary expertise. In March 2020, the Portuguese Foundation for Science and Technology (FCT) launched the AI 4 COVID19, a competition with a budget of EUR 3 million (USD 3.6 million) for R&D projects in the field of data science and AI that contribute to improving the response of public administration bodies to the impact of COVID-19 and future pandemics.

Paunov and Planes-Satorra (2021[5]) analyse the experimental use of new tools and data for policy purposes during the COVID-19 crisis, and the opportunities they bring for the future of STI policy.

(4) Measures to tackle the spread of misinformation

In 2020, in a landscape of social media and continuous news feeds, the publication of false or inaccurate claims based on scientific evidence of bad quality or based on misinterpreting scientific evidence led to a quick spread of misinformation on COVID-19 through social media platforms and private messaging apps, with negative implications for public health. Research suggests that hundreds died because of wrongly believing certain products to be a cure against the pandemic (Islam et al., 2020[43]).

Tackling the spread of inaccurate and false information matters if citizens are to follow sound advice and comply with the confinement and other measures implemented by public authorities, which are based on timely scientific advice. It is also critical to prevent the spread of anxiety and panic among the population, and to protect citizens from the potentially negative effects that non-tested treatments or remedies may have on their health. Governments and social media outlets themselves (sometimes in collaboration) implemented a number of measures to stop the spread of misinformation (see OECD (2020[44]) for an in-depth analysis).

Most countries created an *official website to provide up-to-date information about COVID-19*. These are often a one-stop-shop where citizens can find official health-related advice (e.g. measures to take in their daily lives to prevent the spread of the virus, how to react if they have symptoms, etc.) and information regarding all the measures taken by national public authorities. Statements are promoted via social media channels (e.g. Twitter, Facebook, Instagram). Examples include the websites created in Australia, Denmark, Finland, France, Korea, New Zealand, the Russian Federation and the United Kingdom. Other official websites include those from ministries of health (e.g. Brazil, Greece, Italy), national or regional health services (e.g. Finland, Norway), and websites for science diffusion (e.g. the Danish Videnskab.dk, the UKRI "Coronavirus: the science explained").

Fact-checking services to counter the spread of inaccurate or false information were set up in some countries. In Germany, the web page of the Federal Ministry of Education and Research about fake news related to COVID-19 is updated regularly and findings are disseminated through social media channels. The US Federal Emergency Management Agency created a Coronavirus Rumor Control website to help the public distinguish between rumours and facts regarding the pandemic. Fact-checking web pages were also created by the Ministry of Health, Labour and Welfare in Japan and the Flemish Agency of Care and Health.

A number of *official chatbots, apps and other tools were developed in collaboration with technology firms*. The World Health Organization launched the WHO Health Alert, a free service on WhatsApp designed to answer questions from the public about COVID-19, and the Verified service to offer prompt and reliable responses based on the latest official health information. Several countries also developed automated chatbots on WhatsApp (e.g. "MyGov Corona Helpdesk" in India), or launched their own COVID-19 app, allowing citizens to easily monitor their symptoms and/or stay up to date with the latest official information and advice (e.g. "HSE COVID 19" in Ireland).

Social media platforms and some businesses implemented their own initiatives to tackle misinformation. On 16 March 2020, Facebook, Google, LinkedIn, Microsoft, Reddit, Twitter and YouTube released a joint industry statement declaring they would co-ordinate and work together with public health authorities around the world to tackle fraud and misinformation on line. These and other firms implemented measures to ensure that users searching for information on COVID-19 in their platforms are directed to reliable sources such as the WHO or national health agencies. For instance, Google launched an emergency alert system, consisting of pop out information boxes that appear in every COVID-19-related search, providing direct links to official information on symptoms, prevention and advice. Social media platforms also deployed machine-learning algorithms to identify the spread of false information on line.

1.2. STI activities in response to COVID-19

(1) Unprecedented success in vaccine development

Efforts aimed at producing a vaccine resulted in an unprecedented success, with vaccine campaigns under way across about 50 countries by the end of December 2020 – less than a year after the start of the pandemic, while it usually takes more than 10 years to develop a vaccine (Wellcome, 2020[45]). The publication of the genetic sequence of the virus by a Chinese-Australian research team in January 2020 allowed scientists worldwide to rapidly engage in different lines of research. At the end of May 2020 131 vaccine candidates were under consideration, 10 of them in clinical evaluation. In early September, the number had increased to 180 vaccine candidates, of which 35 were in clinical evaluation (WHO, 2020[1]). In November, Pfizer/BioNTech, Moderna and Oxford/AstraZeneca announced that their respective vaccines appeared to be highly effective in their trials. Already in August 2020, the Ministry of Health of the Russian Federation approved the Sputnik V vaccine against COVID-19, developed by the Gamaleya National Center of Epidemiology and Microbiology.

The success is due to a variety of favourable developments in the STI ecosystem (Ball, 2020[46]). First, COVID-19 vaccines benefited from decades of research on related coronaviruses (in particular from research that began during the SARS and MERS outbreaks in 2003 and 2012), on new vaccine technologies (mRNA vaccines) and on improvements in conventional ones (vaccines containing viral proteins or chemically inactivated SARS-CoV-2 virus). Two of the COVID-19 vaccines that had received regulatory approval in December 2020 (Pfizer/BioNTech and Moderna) use a new technology (mRNA) that has never before yielded licensed vaccines and that can be manufactured more quickly than conventional vaccines.

Second, large amounts of public and private funding were provided for vaccine development, allowing firms to run different phases of trials (pre-clinical, and phases I, II and III) in parallel instead of sequentially. This would be financially unviable for companies under normal circumstances. Moreover, high COVID-19 infection rates helped test the efficacy of vaccines in the final stages of trials, which require the participation of thousands of people. The fact that the virus mutates relatively slowly also contributed to the rapid success in vaccine development (Callaway, 2020[47]).

Third, the existence of national and global institutions created in the past to facilitate research coordination in the event of an infectious-disease threat –including CEPI, launched in 2017 in the aftermath of the Ebola outbreak– allowed rapidly coordinating national and international efforts to develop COVID-19 vaccines.

Fourth, the global emergency also led to accelerated regulatory approval processes for vaccines without compromising on safety. Emergency-use regulations were applied to approve early vaccines, which require companies to conduct follow-up surveys to ensure its continuing efficacy and identify possible side effects. While approval processes differ across countries, efforts have been made in recent years to coordinate and harmonise some of their processes. In 2012, member states of the World Health Organisation established the International Coalition of Medicines Regulatory Authorities (ICMRA) to enhance information sharing and agree on approaches across regulators. In the case of

COVID-19, regulators have reached consensus through the coalition on a diversity of matters, including the best end points for vaccine trials and the continuation of trials after vaccines are rolled out (Nature, 2020[48]).

Fifth, preparations started early on to ensure vaccines could be produced at scale as soon as they would receive regulatory approval. Governments from many countries signed bilateral advanced purchase agreements with vaccine manufacturers (The Economist, 2020[49]). The COVAX Facility, created jointly by the World Health Organisation, CEPI and the Global Alliance for Vaccines and Immunisation (Gavi, a public-private partnership for vaccine development), offered demand guarantees to vaccine manufacturers in order to provide incentives and assurances to manufacturers to expand their production capacity and so bring vaccines to the market faster (see Section 3.3 below) (WHO, 2020[50]). Other investments were made early on to ensure manufacturing capacity of vaccines. For instance, in June 2020, CEPI signed an agreement with the Stevanto Group (an Italy-based producer of pharmaceutical glass containers) to supply 100 million glass vials for the COVID-19 vaccine. By 22 October 2020, it had also signed agreements with Biofabri (Spain), SK Bioscience and GC Pharma (both from Korea) to reserve vaccine manufacturing capacity to produce more than 1 billion doses of any COVID-19 vaccine (CEPI, 2020[51]).

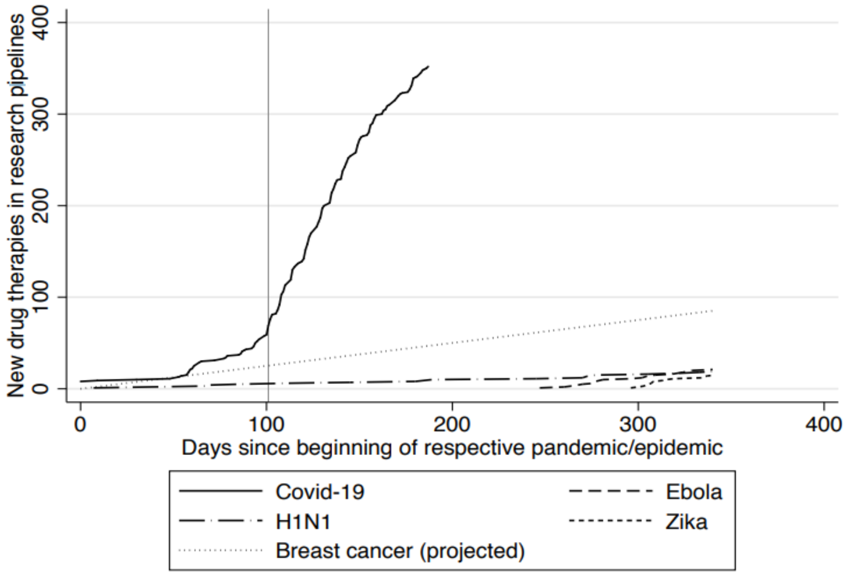
(2) A major R&D and innovation effort to develop COVID-19 treatments and diagnostics

Aside from efforts aimed at developing vaccines, universities, public research institutions and pharmaceutical and biotech firms –sometimes in collaboration – have engaged in R&D efforts to rapidly develop new treatments for COVID-19, with mixed success (Callaway et al., 2020[52]). More than 200 therapies were already in development in April 2020. A study found that the entry rate of new therapies between 11 March and 22 April 2020 was 15 to 80 times faster than those for the three recent epidemics (Zika, Ebola and H1N1) in the year following their outbreaks, or the average past-decade rate for breast cancer therapies (Figure 1) (Bryan, Lemus and Marshall, 2020[2]). As of 21 April 2020, more than 500 clinical trials had been registered at the various international and national clinical trial registry sites (Thorlund et al., 2020[53]). By 21 September 2020, the cumulated number of clinical trials had increased to nearly 5 800 according to the WHO International Clinical Trial Registry Platform (WHO, 2020[54]).

Significant R&D efforts were also devoted to developing more efficient and accurate COVID-19 diagnostic tests, both for detection of active infection and antibodies (Carter et al., 2020[55]). Diagnostic capacities increased rapidly across countries over the first six months of the pandemic, based on the application of a technique called reverse-transcription polymerase chain reaction (or RT-PCR). Yet the scalability of this technique is limited, as it requires trained personnel and specific chemical supplies and instruments only available in specialised laboratories. Research groups devoted important efforts in devising new diagnostics methods, including rapid tests that could be performed by people at home [see Guglielmi (2020[56]) and Vandenberg et al (2020[3])]. By 15 December 2020, the FDA had issued emergency use authorisations for about 225 diagnostic tests for COVID-19 (FDA, 2020[57]).

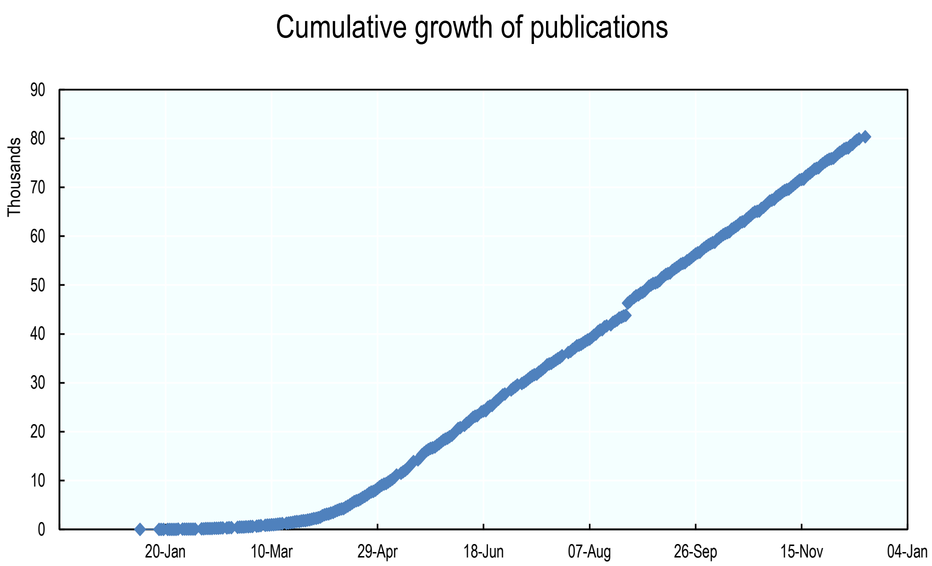
The active engagement of the scientific community is reflected in the number of scientific publications related to the virus. By mid-April 2020, more than 3 500 COVID-19-related articles had been published in medical academic journals, a higher rate than for previous pandemics according to PubMed, a free resource supporting the search and retrieval of biomedical and life sciences literature by the US National Library of Medicine (Bryan, Lemus and Marshall, 2020[2]). By mid-December 2020, the number of PubMed articles related to COVID-19 amounted to around 80 000 (Figure 2) (Chen, Allot and Lu, 2020[58]).

Figure 1. Number of drug therapies (at all stages of development) in research pipelines, by disease



Note: The beginnings of the respective epidemics are 1 December 2019 (COVID-19), 1 April 2015 (Zika), 1 December 2019 (Ebola), and 1 January 2009 (H1N1). COVID-19 therapies measured as of 15 June 2020. The projected number of breast cancer drug therapies are provided as a reference and are computed using the formula entry_rate*time, where entry_rate is the average number of new breast cancer drug therapies per day between the years 2007 and 2016. The vertical line indicates 11 March 2020, the date the WHO declared a global pandemic.
Source: Bryan, Lemus and Marshall (2020[2]), based on data from BioMedTracker and Pharmaprojects.

Figure 2. Number of scientific articles on COVID-19 listed in PubMed, January-November 2020

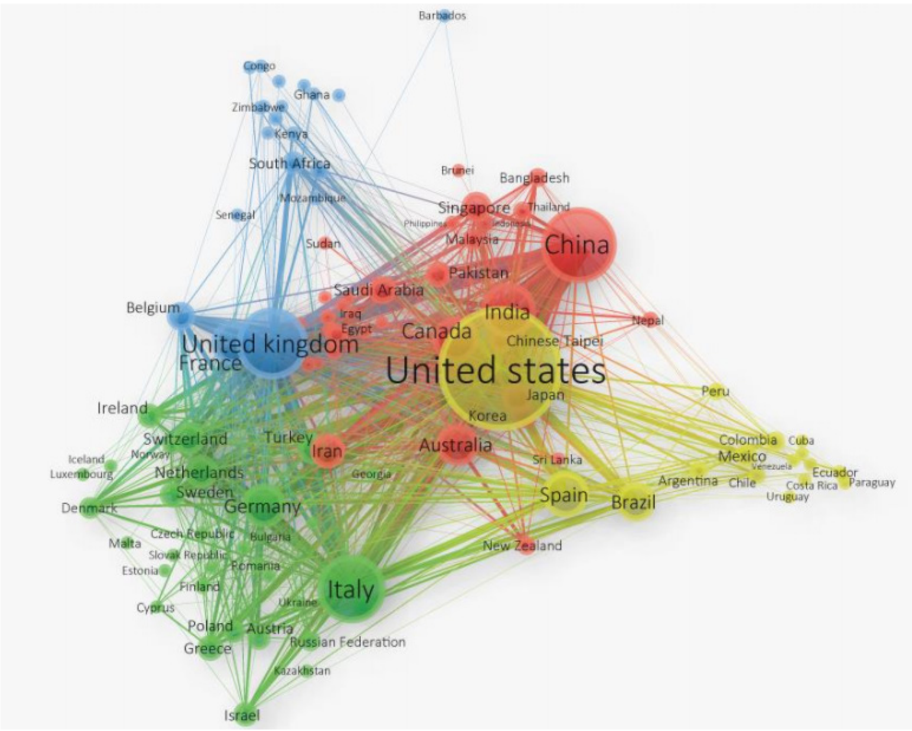


Source: Chen, Allot and Lu (2020[58]).

Preliminary evidence also suggests that collaborative research (including across borders) increased in this context. Bryan, Lemus and Marshall (2020[2]) – based on data from BioMedTracker and Pharmaprojects, two online platforms that track drug development – found that 40% of drug therapies for COVID-19 (covering January to April 2020) were developed by a team of firms (significantly higher than 21% for H1N1 therapies, 9% for Ebola, and 11% for Zika). They also found that about one-third of these collaborations were new, while two-thirds were teams that had collaborated before. Fry et al. (2020[59]) analyse scientific articles on COVID-19 that were published in the period from 1 January 2018 and 8 April 2020 and available on Clarivate Web of Science, Elsevier Scopus and PubMed pages. The authors find that the United States and the People's Republic of China, the two major contributors to COVID-19 research in terms of number of publications, increased the levels of international collaboration with each other following the outbreak (compared to coronavirus research conducted prior to the COVID-19 pandemic), although they seem to be collaborating less with researchers in other nations, particularly from developing countries. Other countries with high engagement in international research collaborations include the United Kingdom, Germany, France, Italy, Australia, Canada and India (Figure 3).

Figure 3. Network of international scientific collaboration on COVID-19 biomedical research

Whole counts, January to 30 November 2020



Note: A map with four clusters, also known as communities, was created based on economy affiliation bibliographic data. Economies are assigned to clusters based on their interconnection. The colour of an item is determined by the cluster to which it belongs. The higher the weight of an item, the larger its label and circle. Lines between items represent links. In general, the closer two economies are located to each other, the stronger their relatedness. The strongest co-authorship links between economies are also represented by lines. Note that the territory attribution for these indicators is entirely based on country affiliation information reported by the authors and publishers as registered on PubMed. Please refer to https://doi.org/10.1787/888934223099 for more methodological information.

Source: OECD (2021[6]). OECD and OCTS-OEI calculations, based on U.S. National Institutes of Health PubMed data, https://pubmed.ncbi.nlm.nih.gov/ (accessed 30 November 2020).

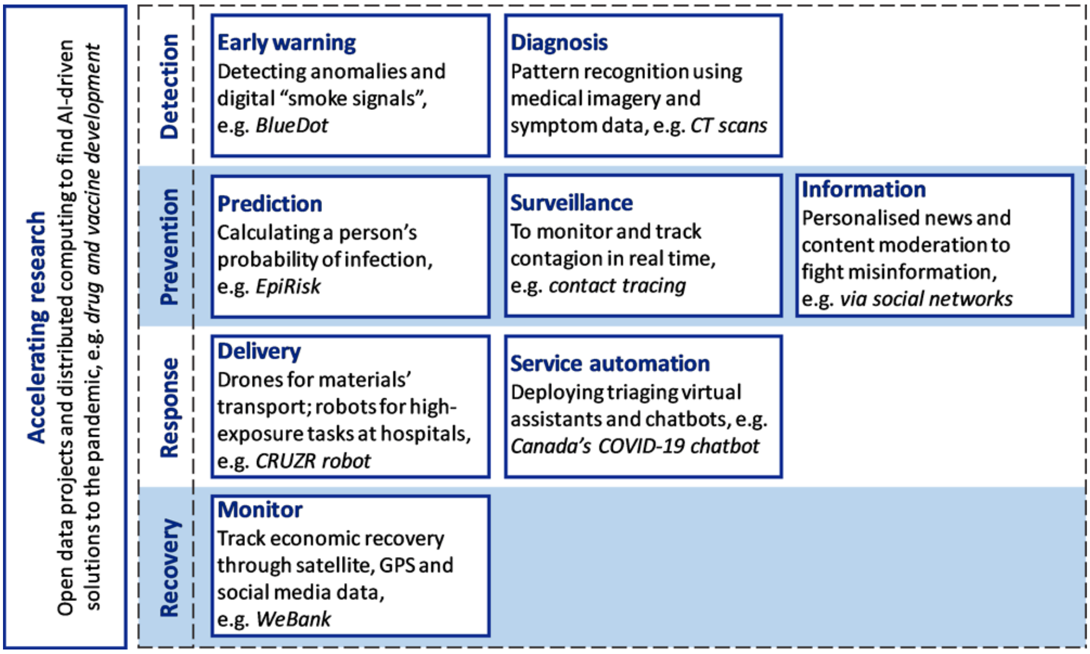
(3) Mobilisation of research and innovation across other disciplinary fields

The challenges of "managing" the COVID-19 crisis swiftly resulted in a wider engagement of researchers in other disciplines – including social and behavioural sciences – and data and machine learning experts. Issues included reducing and resolving the widespread socio-economic costs associated with "social distancing" measures and preventing the virus transmission by changing behaviour and combating misinformation. Those contributing included economists, engineers and psychologists (Coyle, 2020[60]). Social and behavioural sciences for instance have provided innovations for managing the pandemic and its impacts, among others by helping decision makers employ effective leadership, respond to different social contexts and needs, and improve their communication of science (Bavel et al., 2020[61]). Specific outlets to quickly disseminate those COVID-19-related materials were created, such as "Covid Economics: Vetted and Real-Time Papers" launched by the Centre for Economic Policy Research, and the Economics Observatory COVID-19 website set up by the UK Economic and Social Research Council.

AI experts have also mobilised to tackle COVID-19. AI applications have been used among others to help accelerate drug and vaccine development; identify virus transmission chains; rapidly diagnose COVID-19 cases; monitor broader economic impacts; and tackle misinformation (Figure 4) (OECD, 2020[62]; Lee, 2020[63]). Based on a dataset built at the end of May 2020 comprising 1.8 million papers from three preprint repositories (arXiv, bioRxiv and medRxiv), Mateos-Garcia, Klinger and Stathoulopoulos (2020[64]) find that more than a third of AI publications related to COVID-19 involve predictive analyses of patient data, in particular medical scans. The analysis however also shows that AI papers tend to receive fewer citations than other papers on the same topic.

In order to strengthen the linkages across different science fields and so accelerate responses, some governments have launched specific calls to support multidisciplinary research – such is the case with the German Research Foundation (DFG).

Figure 4. Examples of AI applications at different stages of the COVID-19 crisis



Source: OECD (2020[62]).

(4) Frugal innovations

During the first months of the pandemic in early 2020, frugal innovations emerged – which in this case refers to improvised production processes to address product shortcoming in the absence of sufficient production capacities to respond to global demand (Harris et al., 2020[65]). Start-ups in the digital tech sector were particularly flexible in providing rapid responses. In mid-March, an Italian start-up reverse-engineered a 3D printed version of a respirator valve and supplied 100 of those to a hospital in Chiari within a few days. Soon after, the team engineered an emergency ventilator mask, modifying a snorkelling mask already available on the market from Decathlon, a French sporting goods retailer (Isinnova, 2020[66]).

Large manufacturing firms also engaged in efforts. Some firms in the automotive, aviation and consumer goods sectors repurposed (part of) their production lines to manufacture urgently needed medical equipment, such as ventilators and respirator equipment, masks, protective face shields and hand sanitiser. For instance, luxury brands such as the French LVMH switched from producing perfume to making hand sanitiser. In the United States, General Motors repurposed their activities to produce ventilators. Such production adjustments differed in terms of complexity (Betti and Heinzmann, 2020[67]).

Volunteer researchers and innovators also contributed in frugal innovation efforts to jointly develop solutions in the early phase of the pandemic. In Spain, Coronavirusmakers was an open source community founded in March 2020 by civil society that gathered more than 20 000 volunteer researchers, developers and engineers. With the support of firms, public administration and foundations, by 15 May 2020 the group had produced more than 840 000 face shields and 123 000 hands-free door openers. Similar initiatives include Helpful Engineering and Crowdfight COVID-19.

(5) Open science to address COVID-19

Open science initiatives have also proliferated in response to the crisis (OECD, 2020[68]). They aim to accelerate research and innovation and enhance synergies while avoiding duplication of research efforts.

Several data- and research-sharing initiatives were launched to share epidemiological, clinical and genomics data, as well as related studies. Protocols and standards used to collect the data are also being shared. In January 2020, 117 organisations (including journals, funding bodies and centres for disease prevention) signed a statement titled "Sharing research data and findings relevant to the novel coronavirus outbreak", committing to provide immediate open access for peer-reviewed publications at least for the duration of the outbreak; to make research findings available via preprint servers; and to share results immediately with the WHO. This was followed in March by a call from chief science advisors of 12 countries for publishers to make all coronavirus-related research and data freely and immediately available to the public via major platforms in machine-readable formats. More than 50 publishers responded, depositing content into the US National Library of Medicine's PubMed Central archive for full-text biomedical literature (OECD, 2020[68]; Funk, 2020[69]).

The COVID-19 Open Research Dataset (CORD-19), created by the Allen Institute for AI, the National Library of Medicine, the Chan-Zuckerberg Initiative, Microsoft, and Georgetown University's Center for Security and Emerging Technology (CSET), at the request of the White House Office of Science and Technology Policy, contained at the end of September 2020 over 200 000 machine-readable scholarly articles on COVID-19 and related coronaviruses, including over 100 000 with full-text (The White House, 2020[70]). The dataset serves as a basis for applying machine-learning techniques to generate new insights to support COVID-19 research. The COVID-19 Open Research Dataset Challenge hosted on the Kaggle platform allows AI researchers to generate new insights in support of the ongoing fight against the pandemic (Kaggle, 2020[71]). Other initiatives include repositories of genome data (such as Nextstrain and Gisaid), chemical structure data (such as the CAS COVID-19 antiviral candidate compounds dataset), clinical studies (such as the US National Institutes of Health's ClinicalTrials.gov COVID-19-related studies), and data for modelling research (such as MIDAS).

The rapid surge of data and studies related to COVID-19 posed the additional challenge of how researchers should best process this wealth of information (Brainard, 2020[72]). Several initiatives have emerged to facilitate the exploration of such data using new, user-friendly tools, such as SciSight – a visualisation tool that allows exploring the fast-evolving literature network around COVID-19 posted in CORD-19. The annual Text Retrieval Conference (TREC), organised by the US National Institute of Standards and Technology, aimed to improve search engines for COVID-19 research (NIST, 2020[73]).

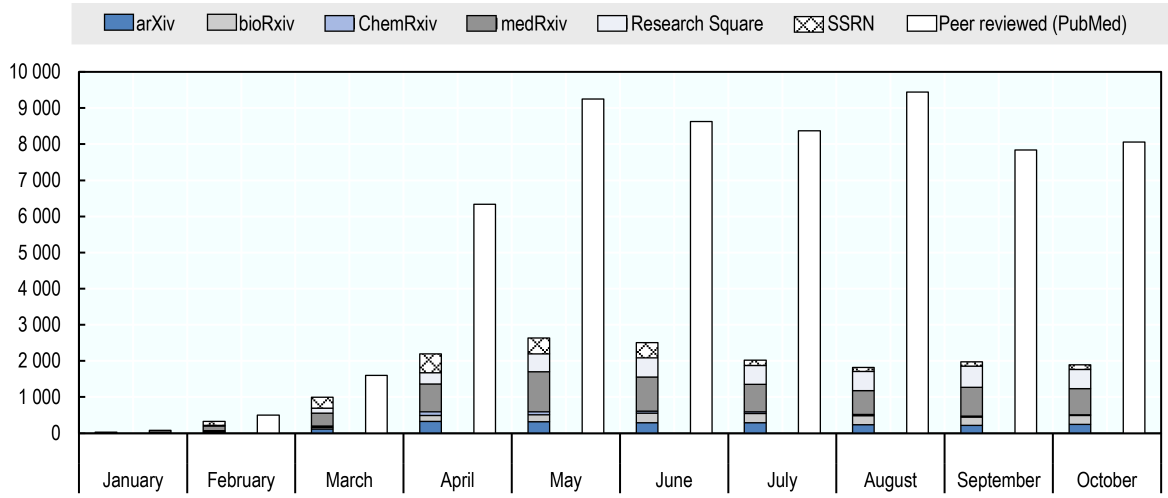
Finally, while efforts aimed at making data and research widely accessible reached unprecedented levels, not all research relevant to COVID-19 is easily findable, accessible, interoperable and reusable (FAIR). Moreover, data sharing still suffers from a lack of specific standards, co-ordination and data quality (OECD, 2020[68]).

(6) Quick diffusion of research results and its use by policy

An important change brought about by the pandemic has been the greater speed with which scientific research results have been released. Many journals have accelerated their peer-review process to ensure rapid dissemination. Based on data from 669 articles published in 14 medical journals[4] both prior to and during the COVID-19 pandemic (until April 2020), a study finds that the time to publish had decreased on average by 49%, from 117 to 60 days (Horbach, 2020[74]). According to another study, the median time to acceptance for COVID-19-related articles in Scopus journals in the first half of 2020 was 19.3 days. Comparatively, non-COVID-19-related articles had an average time to acceptance of 91.4 days over the same period (Aviv-Reuven and Rosenfeld, 2020[75]).

Preprints (i.e. academic papers that have not been peer reviewed yet) have become more common in the medical research field since the beginning of the pandemic, allowing for an increased speed of diffusion (also across scientific fields) and for reaching a wider range of potential peers. The rapid adoption of the practice is illustrated by the number of papers posted in MedRxiv, the preprint server for medical research created in June 2019 by the Cold Spring Harbor Laboratory, Yale University, and The BMJ. While its first months of operations saw few papers the numbers increased sharply after the COVID-19 outbreak, reaching a monthly peak of 2 000 in April 2020. In that month, the site received around 15 million page views, up from 1 million before the pandemic (Fox, 2020[76]). By the end of May 2020, 26% of the COVID-19 papers listed on the NIH COVID-19 Portfolio were preprints; by comparison, the proportion of biomedical preprints vs. the published literature in PubMed stood at 3% in 2019 (Figure 5) (ASAPbio, 2020[77]).

Figure 5. COVID-19 preprints vs. peer-reviewed (PubMed) papers, per month



Note: The figure is based on data from the NIH COVID-19 Portfolio. It allows comparing the number of COVID-19-related articles from PubMed and the preprints from arXiv, bioRxiv, ChemRxiv, medRxiv, Research Square, and SSRN by month.
Source: NIH (2020[78]).

The acceleration in journal review processes and in the distribution of preprints raised concerns regarding the possible spread of low-quality scientific evidence. As of 31 July 2020, 19 published articles and 14 preprints about COVID-19 had been retracted or withdrawn, or had generated concern, for a range of reasons including data falsification and questionable methodology, interpretation of data and conclusions (Bramstedt, 2020[79]). Regarding quality, a 2019 study finds however that 67% of preprints posted on the BioRxv server between 2013 and the end of 2016 were eventually published in scientific journals (Abdill and Blekhman, 2019[80]). Another study finds that 65.7% of preprints in the field of computer science submitted to arXiv from 2008 to 2017 were later published in peer-reviewed venues with the same titles, and 11.4% under changed titles and with other modifications (Lin et al., 2020[81]). These findings suggest that on average the difference in quality between preprints and studies published in scientific journals is not too large.

Several steps were taken to reinforce the quality checks of early scientific evidence published online. Preprint repositories adopted additional screening procedures to ensure that potentially harmful information would not get published. New initiatives were also launched to increase the quality of preprints relating to COVID-19, such as the Outbreak Science Rapid PREreview – a platform where researchers with relevant expertise can volunteer to provide swift reviews (Kwon, 2020[82]). Another example is the MIT Press Rapid Reviews: COVID-19 (RR:C19) – an open access overlay journal that seeks to accelerate peer review of research preprints to prevent the spread of false information. It uses AI tools and a network of scholars to identify the most promising papers in preprint repositories, submit them for expert peer review, and then validate findings before making them publicly available (MIT Press, 2020[83]).

Another important change brought about by the pandemic is that academic and scientific discussion of research results and how to address emerging challenges went virtual, as seen with the multiplication of online conferences and workshops related to COVID-19 during 2020. Some of these had very high attendance (see further explanations in Section 2.1 below). For instance, more than 30 000 followed a virtual conference organised by the Stanford Institute for Human-Centered Artificial Intelligence in April 2020, to discuss how AI could help scientists fight the pandemic (Price, 2020[84]).

New scientific evidence rapidly fed into policy making during the pandemic. An analysis of policy documents published from January to May 2020 by government agencies and think tanks from 114 countries and 55 intergovernmental organisations finds that COVID-19-related policy documents extensively cite very recent, peer-reviewed and high-impact science. The close connection between science and policy was also reflected in the fields of science cited in COVID-19 policy documents – shifting from mainly drawing on biomedical literature in the first months of 2020 to increasing the focus on economics, society and other fields of study as the relevance of socioeconomic aspects of the pandemic was recognised more (Yin et al., 2020[85]).

2. Impacts of COVID-19 on STI systems, and the policy responses

This section explores the effects of the crisis on STI systems in 2020, as well as policy measures implemented to tackle them. It draws from the data and evidence available, as well as country responses to the OECD Survey on STI Policy Responses to COVID-19. The remainder of the section discusses 1) impacts on research and higher education institutions, 2) impacts on innovative businesses and entrepreneurs, 3) the unequal effects of the crisis on STI actors, and 4) the policy measures that have been implemented in different countries to support those most affected by the crisis.

2.1. Impacts on research and innovation activities of universities and public research institutions

The impact of COVID-19 on research institutions in 2020 was one of limited access to infrastructure and tools, reduced labour productivity, diversion of research efforts towards COVID-19 topics, restricted mobility of researchers, and disruptions in human capital training. The magnitude of the costs to research was partly attenuated by the use of digital tools to address each of those barriers.

(1) Reduction in research productivity and limited access to research infrastructures

Research and innovation activities requiring physical access to laboratories and other research facilities,[5] as well as those involving field work or clinical trials,[6] were highly disrupted by lockdown and social distancing measures – except for activities directly addressing the COVID-19 health emergency and others considered essential to protect (World Bank, 2020[86]). The latter include activities where an interruption severely impedes research delivery (e.g. long-term experiments) and those that require ongoing supervision for regulatory, safety or health requirements (e.g. care of living specimens, research that uses hazardous materials).

Where those access restrictions applied, researchers shifted to activities that can be conducted at a distance from the home office (Stenvot, 2020[87]). A survey conducted by ResearchGate in March 2020 with data from 3 000 international researchers across academic fields suggests that, in the initial phase of the first global lockdown, nearly half of them replaced on-site activities with an increased focus on writing, analysis, publishing and planning for future research. Some were also spending more time analysing older sets of data that had not been explored previously where new research data cannot yet be gathered (Research Gate, 2020[88]) (Baynes and Hahnel, 2020[89]).

Limited access to research infrastructures also affected the ability of recipients of R&D loans and grants to deliver results in the expected timescale, and of those preparing research proposals to have them ready by the deadlines. In response, research funding institutions introduced a number of flexibilities. For instance, the European Commission postponed application deadlines for most calls to give more time to applicants to prepare their proposals, and the Research Council of Norway released a range of measures and principles to assist grant holders and applicants with new projects to deal with challenges posed by the COVID-19 pandemic (e.g. projects that experience delays, cannot be carried out as planned, or need to be put on hold) (Research Council of Norway, 2020[90]).

Final-year PhD students and postdoctoral researchers also faced challenges to finalise their programmes on time, particularly if these required field or lab work, and to access academic and research positions, as many universities cancelled or postponed recruitment processes (see Section 2.3) (Yan, 2020[91]). A survey conducted in April 2020 based on responses from 4 800 doctoral researchers and research staff in the United Kingdom found that more than 60% were very worried about their future research plans, and 70% about their finances. It also found that the levels of mental distress were higher among doctoral researchers compared to research staff (Smarten, 2020[92]). With restrictions on movement in place for most of 2020, challenges for research based on field work remained substantial.

In addition, while some research and innovation activities could be partly or fully performed remotely (e.g. data analysis, writing papers), in many cases labour productivity slowed down , due to the closure of childcare facilities and schools during periods of lockdown, higher levels of anxiety and depression linked to isolation and fear, and the loss of the benefits that creativity and innovation draw from face-to-face interactions (OECD, 2020[93]) (Gorlick, 2020[94]). For instance, a survey of full-time employees and executives at the Japanese Research Institute of Economy, Trade and Industry (RIETI) conducted in March 2020 found decreased self-reported worker productivity when teleworking during lockdown compared to working in the office (Morikawa, 2020[95]). Women researchers, especially those with children, were significantly more affected by lockdowns implemented in 2020 than their male peers (see Section 2.3 on the unequal effects of the crisis on the STI labour force).

(2) Diversion of research efforts toward COVID-19 topics

The flipside to the research community's widespread efforts to fight the virus is the risk of diverting those efforts away from non-COVID-19 topics. This applies to the medical field but other science fields as well. Madhukar Pai, Director of the McGill Global Health Programs, referred to this threat as the "covidisation" of research (Pai, 2020[96]). Driven partly by extensive and dedicated funding for COVID-19-related research, this redirection of purpose can translate into expertise simply not being invested in other topics. An international survey tracking researcher attitudes conducted by Springer Nature and Digital Science from 24 May to 18 June 2020 collected 3 436 responses from researchers in different disciplines; it found that 43% of those surveyed either had already repurposed their grants for COVID-19 research or were likely to (Baynes and Hahnel, 2020[89]). In addition to the proliferation of articles on COVID-19, the magnitude of the shift is illustrated by the fact that 41% of 424 universities across 105 countries responding to a survey implemented by the International Association of Universities from 25 March until 17 April 2020 were engaged in COVID-19 research (Marinoni, van't Land and Jensen, 2020[97]).

Research deviation away from other important fields of research is also partly due to the closure of research facilities (beyond those considered essential to address the COVID-19 health emergency) and the suspension of clinical trials during the first months of the pandemic. In the United Kingdom alone, around 9 000 clinical trials of new drugs and treatments for cancers, heart disease and other illnesses (or around 60% of the total) were suspended when COVID-19 hit the country, and will require sizable investments to be reactivated. More than 1 500 clinical trials were permanently closed down by August 2020 (McKie, 2020[98]). In December 2020, Cancer Research UK, whose fundraising activities were disrupted by COVID-19, reported a significant decrease in planned annual research spending, from pre-COVID levels of GBP 400-450 million (USD 544 – 612 million) to around GBP 250 million (USD 340 million) (Burki, 2021[99]). In the United States, the Cancer Research Institute registered 958 stopped clinical trials due to COVID-19 from March to September 2020 (Cancer Research Institute, 2020[100]). Seeing their labs shut down, some scientists and their institutions decided to donate their time and expertise to fight the coronavirus, and repurposed their facilities and equipment to serve that cause.

(3) Restricted researcher and student mobility

Severe restrictions placed on the movement of researchers by lockdown measures interrupted the mobility of human resources in STI (e.g. visiting researchers, staff exchanges with industry). In 2020, many scientific events and conferences were either postponed, cancelled or organised in virtual format. Some virtual events had very high attendance beyond participant numbers in pre-pandemic in-person events. For instance, the American Physical Society (APS) counted more than 7 000 registered participants for its April 2020 meeting held on line, significantly higher than the 1 700 that would on average attend the in-person meeting (Castelvecchi, 2020[101]). Such a move has emphasised the advantages of digital conferences (in particular improved accessibility, greater reach to more diverse audiences, lower cost, reduction in the carbon footprint of travel), although virtual exchanges are not perfect substitutes for in-person conferences. The latter are often the origins of collaborations and long-term trusted relationships; for early career researchers, they also are an opportunity to find jobs and make their work known.

The reduction in researcher mobility put on hold many research collaborations and research requiring field work, thereby delaying scientific output – although impacts significantly differed across disciplines. Some, such as data analytics, were less affected, while research projects involving ocean and space expeditions, or fieldwork in remote areas, were highly disrupted. For instance, the pandemic temporarily interrupted the polar research expedition MOSAiC, involving hundreds of researchers from 20 countries, and the 2020 EastGRIP mission, an international multi-year effort to measure glacier flows in Greenland, was cancelled (Jordans, 2020[102]; EastGRIP, 2020[103]) (Stone, 2020[104]). This can have particularly severe impacts on long-term science data-gathering efforts. Regarding the immediate effects of COVID-19 on partnerships, the aforementioned survey from the International Association of Universities suggests that these effects were mixed. Of the 64% of universities that identified effects of the pandemic on partnerships, half reported that COVID-19 weakened them, while 18% reported that it strengthened them and 31% said that new opportunities with partner institutions had emerged (Marinoni, van't Land and Jensen, 2020[97]).

Most study abroad, exchange and fieldwork programmes planned for 2020 were also interrupted or suspended. International students already in their host country at the beginning of the outbreak were highly affected by the lockdown, as campuses closed down and many were unable return to their home countries or faced other challenges (e.g. reimbursement of accommodation fees). Most universities set up support services to ensure students' physical and mental well-being. Suspension of international programmes may prevent those directly affected from developing the range of skills acquired during those experiences. Effects may moreover disproportionally affect those from disadvantaged backgrounds, who are less likely to engage in similar activities in the future without financial support. Uncertainty regarding future developments may reduce overall student mobility beyond 2020.

(4) Rapid shift to online learning and financial challenges

As universities were forced to shut down their campuses as the COVID-19 pandemic spread across countries, they had to move quickly to adopt online education tools – a move sometimes costly. Particularly for universities that had not previously engaged in online teaching, adjustments were substantive, as digital tools needed to be gathered and online teaching schedules implemented to compensate for on-campus training. This process was highly time-consuming, diverting efforts of faculty members from research into training activities to acquire the necessary skills to deliver online learning courses and preparing and the necessary materials when these were previously non-existent. Other important related challenges included setting up robust remote assessment methods, online support systems in areas such as academic advising and tutoring, and alternative admission practices for incoming students (where these previously involved in-person exams or interviews). Most universities and research institutions established specific task forces to design tailored measures to mitigate the impact of the pandemic on their students and institutions.

In most countries, universities moved to fully virtual or hybrid programmes for the 2020-21 academic year. The long-term impacts will depend on the quality of online teaching, which may be highly unequal across institutions, as well as how it reaches students to build future human capital for research and innovation. Indeed, as the system moves to online learning, there is the risk of widening digital divides in connectivity and access to devices among university students, which are largely a reflection of socio-economic disparities. Those from the most disadvantaged backgrounds are more likely to drop out from the higher education system if not provided with specific support, which can have implications in reducing the inclusiveness of science and innovation systems in the future. Many universities have introduced measures to provide computers and additional support to those students.

Universities also faced major financial uncertainties in 2020 due to uncertainties about their income from student tuition fees as well as industry and public resources. Substantial reductions in income, possibly accompanied by reductions in funding from research (e.g. contract research, grants), were expected for universities that relied heavily on student tuition fees (especially those with an important share of international students). Countries where universities critically rely on such funding include the United Kingdom, Ireland, the United States, Canada and Australia. (Halterbeck et al., 2020[105]) (Larkins and et al., 2020[106]). Universities in continental Europe and other countries were expecting more fiscal pressure from lost contractual research and granting opportunities. A total of 29 national university associations surveyed in summer 2020 by the European University Association reported that they expected contractual resource funding to decline as a result of COVID-19, pointing to public funding making up a greater share of their resourcing moving forward (Pruvot et al., 2020[107]).

Regarding the actual evolution of financial resources, some students deferred or abandoned or postponed their plans to engage in higher education programmes in 2020-21 (Jaschick, 2020[108]). Consequently, universities in the United States estimate the financial impact of the pandemic up until September 2020, in terms of additional costs and foregone revenue, to have totalled USD 120 billion by the end of September 2020 (Mitchell, 2020[109]). In the fall 2020 semester, the number of international students enrolled at institutions in the United States decreased by 16% on the previous year, according to a survey . Data on international student permit issuance in Canada indicates, as of October 2020, a decrease of 58% on the previous year, which could translate, according to some estimates, to a 7.5% decrease in university revenue (i.e. a loss of CAD 3.4 billion, or USD 2.7 billion) (Statistics Canada, 2020[110]). A study from Australia reports a decline since April 2020 of 80-90% in international student visa applications when compared to figures from last year. The number of international students enrolled at Australian universities fell by 12% between March and October 2020, and the study extrapolates a further 50% reduction by July 2021, citing ongoing travel restrictions as an important factor (Hurley, 2020[111]). By contrast, in the United Kingdom, for the fall 2020 semester, the number of accepted students from EU countries decreased by 2% only while the number of international students from outside the EU increased by 9% (UCAS, 2020[112]). It is also important to note that a variety of factors beyond the COVID-19 pandemic affected international student intake, including policies on travel and visas. Regarding public funding, financial impacts were so far less severe, although they could be more significant in the mid- to long-term as a result of public budgetary constraints resulting from the COVID-19 crisis, if the evolution is similar to that following the 2008-09 global financial crisis (see Paunov and Planes-Satorra (2021[5]).

2.2. Impacts on firms' research and innovation activities

Firms' research and innovation activities were affected differently by the 2020 COVID-19 crisis, due to a range of factors that include their sector of activity and their financial situation.

(1) Limited access to innovation facilities and in-person research collaborations

As was the case elsewhere in the economy, lockdown measures in 2020 led to the closure of innovation and testing facilities, labs and science parks. Social distancing measures applied afterward also restricted access in many cases. This had a direct impact on firms' ability to progress with planned research, product development and commercialisation activities. Moreover, social distancing reduced the well-known benefits of geographic proximity and regular interaction among innovators, both formal (e.g. during conferences, institutionalised collaborations) and informal (socialisation, random encounters). This also explains why, in spite of digital communication tools, innovation activities are highly concentrated geographically in leading cities (Paunov et al., 2019[11]).

Moreover, similarly to researchers at universities and research centres explored in Section 2.1, the productivity of professionals working in corporate research and innovation activities decreased, even if some activities could continue to be fully or partly performed remotely (e.g. data analysis, programming), particularly for researchers engaged in care-taking activities as a consequence of the COVID-19 crisis.

(2) Investments in research and innovation activities

The COVID-19 pandemic and the related containment measures disrupted business activity across many sectors and across countries (see Section 2.3 for important exceptions). According to evidence from the World Bank Enterprise Surveys conducted in June-August 2020, monthly sales decreased on average around 47% in Italy compared to the previous year, 37% in Greece, 28% in the Russian Federation, and 19% in Poland. Sharp decreases in demand particularly during the lockdown period(s) pushed many firms into financial distress. Many innovative start-ups and technology-intensive firms were also affected. A survey of 1 070 technology-driven start-ups in 50 countries, conducted between 25 March and 17 April 2020, found that more than 40% of these start-ups had three months of cash runway or less (Gauthier and Morelix, 2020[113]).

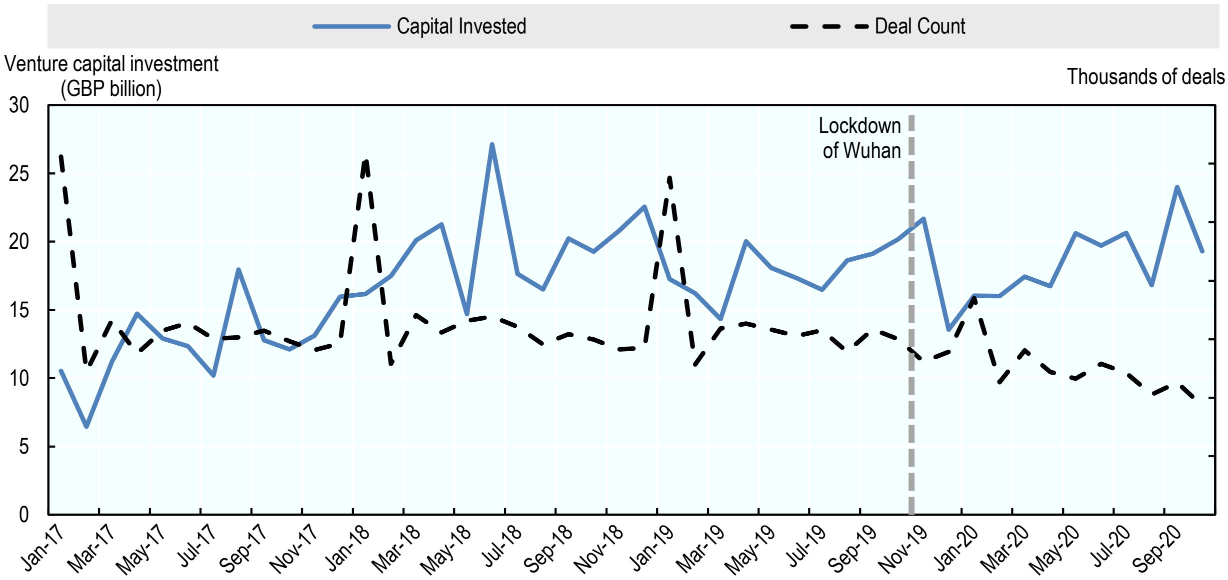
Innovative firms facing financial constraints (and particularly small and young firms) likely cut back on their investments on R&D and innovation projects, and suspended or postponed planned innovation activities. A survey of innovative companies conducted in April 2020 by the German Federal Ministry for Economic Affairs and Energy found (based on 1 800 responses, 86% of which were SMEs) that 54% of companies had suspended ongoing research and innovation projects, and 24% were planning to terminate one or more projects (BMWi, 2020[114]). A survey of about 200 executives across industries conducted in April 2020 found that the focus on innovation as a core business priority decreased across most industries as companies addressed immediate COVID-19-related challenges; the exceptions among the selected set of industries surveyed were the pharma and medical supply sectors (McKinsey, 2020[115]).

Evidence from the 2008-09 crisis confirms that economic downturns have an important negative impact on firms' innovation behaviour, leading a large share to abandon innovation investments (Paunov, 2012[116]). The percentage of firms across Europe increasing their innovation expenditures dropped dramatically as a direct result of the 2008-09 financial crisis, from 40.2% in 2006-08 to 10.6% in 2009. The percentage of firms decreasing investments in innovation rose from 10.8% to 26.7% (Filippetti and Archibugi, 2011[117]). Firms were also less engaged less in university-industry joint scientific production (Azagra-Caro et al., 2019[118]).

(3) Impacts on finance for innovative start-ups

Early evidence across countries suggests that while a slowdown in VC funding activity was observed in the early phase of the COVID-19 shock in March and April 2020, activity generally picked up in the second half of the year Israel is an example: 91% of the 414 Israeli technology companies with less than 50 employees surveyed by the Israel Innovation Authority and the Israel Advanced Technologies Industries (IATI) in mid-May pointed to a slowdown in investor funding, and for 40% investment processes had been halted (Solomon, 2020[119]). Investments increased again in the third and fourth quarter of 2020. Overall, VC investments in the Israeli tech industry amounted to USD 10.2 billion in 2020, 31% more than in 2019 (IVC-Meitar, 2021[120]). A survey of 1 000 mostly US-based institutional and corporate venture capitalists conducted in June and July 2020 also found they had slowed down their investment pace (71% of normal) during the first half of 2020, and expected their investment pace would be 81% of the normal pace for the rest of the year. This suggests that the impacts of the COVID-19 crisis on VC in 2020 were more modest than in the dotcom bust of 2001-02 (when investment declined more than 50%) or during the global financial crisis of 2008-09 (when investment declined by 30%) (Gompers et al., 2020[121]). This is confirmed by global data which shows that the levels of VC investment increased between January and October 2020 (Figure 6). In the major VC hubs of the United States, the United Kingdom, France and Germany, levels of investment between January and October 2020 were almost 20 percent higher than during the same period in 2019 (Ipsos MORI, 2020[122]).

Figure 6. Global venture capital investment, 2017 to October 2020

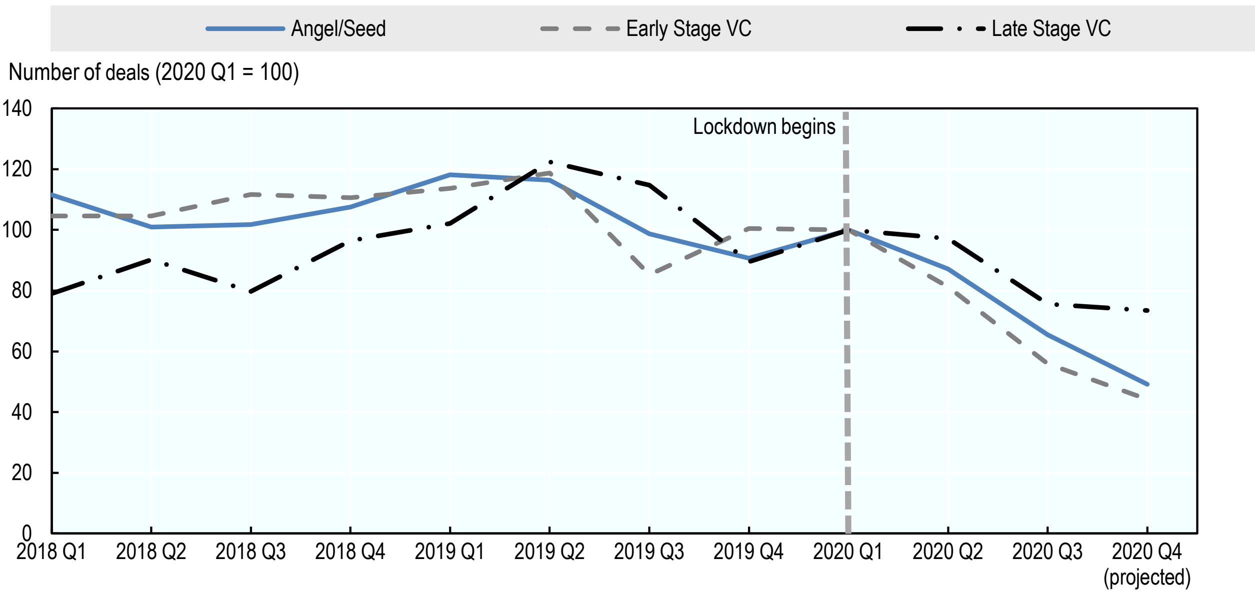


Source: Ipsos Mori based on Pitchbook data.

However, COVID-19 shock did not leave access to capital for all innovative start-ups unaffected. The number of VC deals during the period declined, reaching its lowest levels since February 2013, which suggests a trend towards the concentration of capital in fewer larger deals (Figure 6). Different trends were observed by stage of funding. Seed, angel and early-stage investment kept declining between the first and third quarter of 2020, while late-stage funding increased over the period. For instance, in the United States, the number of early-stage VC deals declined by 38% in March and April 2020, while late-stage VC did not change much even in that early period (Howell et al., 2020[123]). The number of angel and early-stage VC investment deals in UK-headquartered companies fell substantially between April and October 2020, while overall levels of VC investments increased, suggesting that start-ups and pre-revenue firms were hit harder (Figure 7) (Ipsos MORI, 2020[122]). The greater impact of the crisis on early-stage start-ups is consistent with historical data on VC activity in the United States (between 1976 and 2017), which show that aggregate deal volume declines in recessions and that investors who specialise in early-stage deals are significantly more sensitive to business cycles than later-stage investors (Howell et al., 2020[123]).

Figure 7. Number of deals by investment stage, United Kingdom

2020 Q1=100



Source: Ipsos Mori (2020[122]) based on Pitchbook data.

(4) Resilience in innovation and patenting during the 2020 COVID-19 crisis

The evidence available as of October 2020 on firms' innovation activities during the first global wave of COVID-19 suggests that particularly bigger companies have been relatively resilient to the shock. While ongoing research projects often had to be interrupted, many firms reacted rapidly to the new context by introducing process and product innovations that could allow them to maintain part of their activities or respond to new market demands. A survey of 247 professionals and decision makers of patenting companies worldwide conducted in April and May 2020 showed that close to a quarter (23%) of companies had repurposed their innovations in markets beyond their primary industry, such as Internet services, logistics, communications, sanitation productions, and healthcare or hospital services (Kanesarajah and White, 2020[124]). Another survey of 375 UK businesses conducted in July 2020 found that 45% of firms had introduced or improved a product or service between March and July 2020, with 75% of those introducing entirely new products or services, and around 60% improving existing ones (Riom and Valero, 2020[125]). Such innovation activities often involved adoption of digital technologies, as discussed in the subsection below.

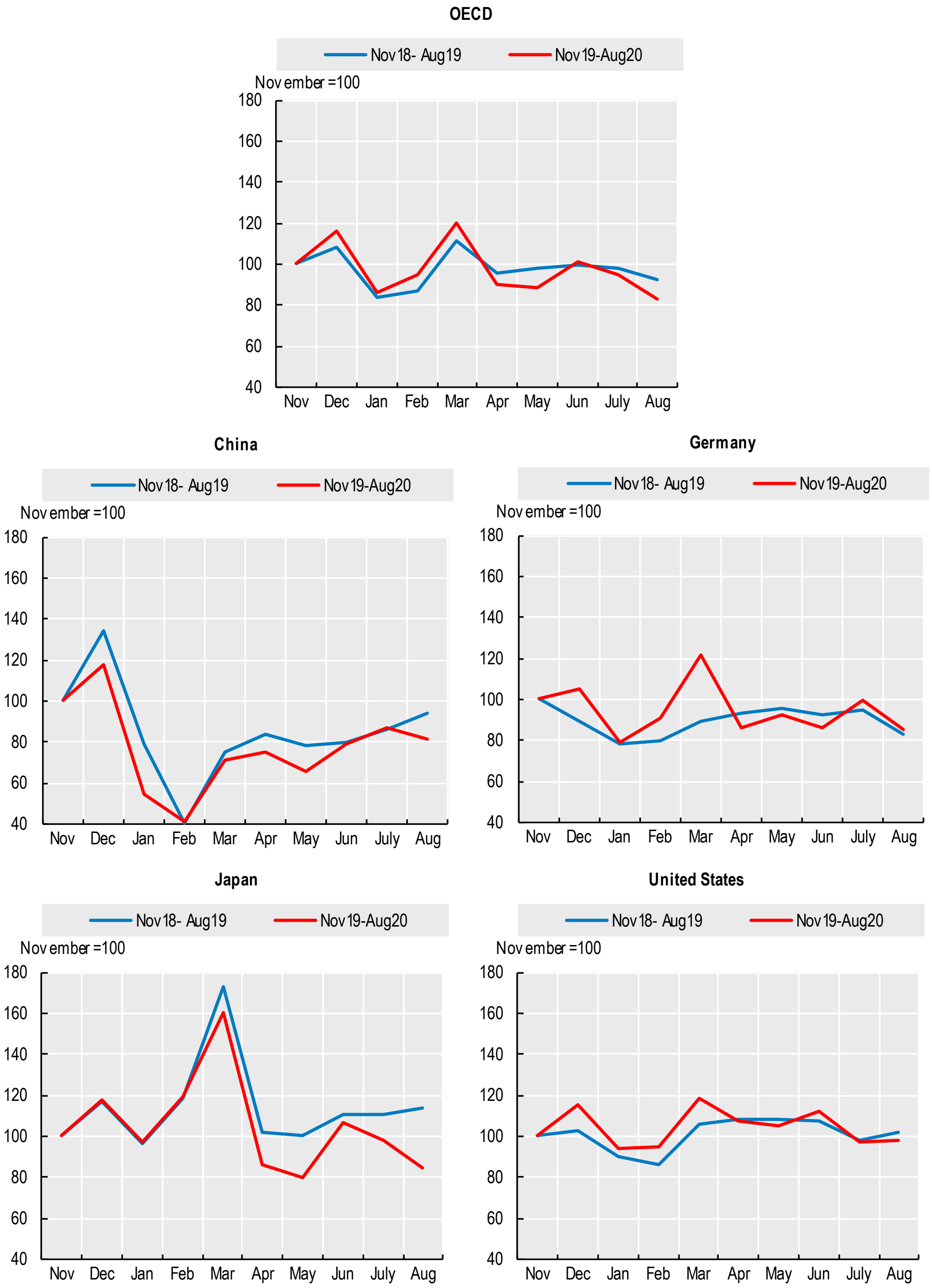
Comparing trends in Patent Cooperation Treaty **(**PCT**)** applications in different countries between November 2019 and August 2020 with the same period in the previous year, Figure 8 shows that on average OECD countries experienced a certain slowdown in patent filings following the COVID-19 outbreak– a trend seen with Germany, Japan, the United States and to some extent China. In the case of China, PCT patent filings went back to the levels registered the previous year already in March 2020, and in the OECD area as a whole the gap with the previous year narrowed in June-July 2020 but widened again in August 2020. Patent applications are in many ways imperfect indicators of what happened in innovation, as effects of possibly reduced innovation investments only translate into fewer patent filings after a time lag. It is therefore not surprising that impacts of the crisis on patenting have been modest in the first half of 2020 even if the

COVID-19 hit innovators. Looking into evidence on trademark registrations is consequently interesting as it is less affected by time lags than patents. Deviations in trademark registrations to the US Patent Office (USPTO) closely mirrored deviations in the US GDP per capita during the 2008-09 crisis (OECD, 2012[126]). In contrast, in the case of the 2020 COVID-19 crisis, preliminary data on aggregate trademark registrations at the Japanese Patent Office (JPO) and the USPTO show that these did not drop in 2020 compared to the previous year (JPO, 2020[127]; USPTO, 2020[128]).

Monitoring evolutions in the coming months will be critical to better understand the impacts of the crisis on technology development and patenting activities, given the time lag from research to invention. Reductions in research and innovation activities due to the pandemic may thus be reflected in patenting applications only in the coming months or years. Evidence from the 2008-09 financial crisis confirms that, with some notable exceptions (e.g. China, Korea), in many countries patent applications declined in the years following the beginning of the crisis. That was the case with the Netherlands, the United Kingdom and the United States, where the number of PCT patent filings in 2010 were considerably below 2007 levels (OECD, 2012[7]). The technologies being patented may also change, as the COVID-19 crisis may have changed incentives to innovate across different areas (as suggested by Figure 9 below, which shows an increase in USPTO patent application filings on technologies that support work from home). Other inventions developed to address COVID-19 may also contribute to inventions across other medical and health fields. The successful application of RNA vaccines to COVID-19, for instance, could lead to a new stream of inventions aimed at immunizing against other diseases (such as HIV, malaria, influenza) (Dolgin, 2021[129]). Paunov and Planes-Satorra (2021[5]) discuss in more detail the possible longer-term implications of COVID-19 for science and innovation.

Figure 8. Trends in PCT patent applications, selected economies

November=100



Note: Data relate to patent applications filed under the Patent Cooperation Treaty (PCT). These figures allow comparing trends in PCT patent filling applications between November 2019 and August 2020 with the same period the previous year. The gaps between the blue and red lines reflect the extent to which annual trends in patenting differed before and after the COVID-19 crisis. Given that patent offices release patent filing information in different periods of the year, the figures should be read with caution – both when interpreting implications of the COVID-19 crisis on patent applications in a specific country/region, and when comparing trends across countries. The figures include all patent applications, including those filed by industry (which account for the largest share of patent applications) and public research.
Source: WIPO Statistics Database

(5) Accelerated adoption and development of digital technologies and tools

The pandemic considerably accelerated the adoption of digital products and services such as videoconferencing, digital collaboration tools, video and entertainment streaming, online shopping, online learning, online gaming and digital fitness apps. For instance Zoom, the online videoconferencing platform, had more than 300 million meeting participants per day in April 2020, up from 10 million in December 2019 (Warren, 2020[130]). Netflix, a video streaming provider, added 16 million new subscribers in first quarter of 2020 (Lee, 2020[131]).

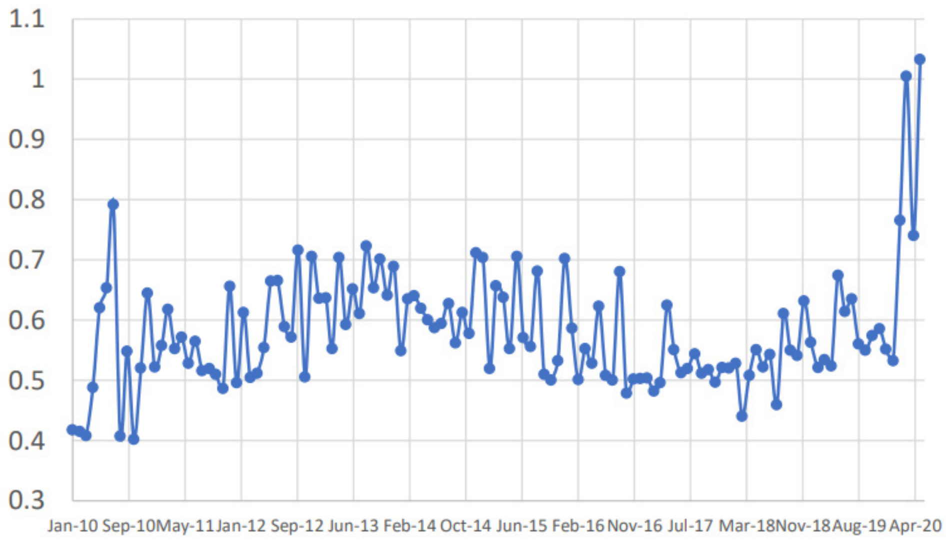
The health and education sectors have been very responsive in adopting digital technologies at an unprecedented rate: since the beginning of the outbreak, the majority of primary care appointments have been delivered virtually, and there has been a surge in the use of apps allowing for remote monitoring of patients' health conditions (Webster, 2020[132]). Similarly, digital tools were rapidly adopted by education institutions (from primary schools to higher education institutions) to ensure continued learning.

An acceleration in the business uptake of digital technologies has also been observed since the pandemic outbreak, including among traditionally low-tech industry segments such as retailers, restaurants, museums and theatres. In some cases these have rapidly adopted online tools in order to maintain (part of) their activities (e.g. being able to receive digital orders and organising home delivery, offering virtual visits and streamed performances). A survey of 375 UK businesses conducted in July 2020 finds that over 60% of firms adopted new digital technologies and management practices, and around a third invested in new digital capabilities. Most firms expect the adoption of such new technologies and practices to be permanent and have a positive impact on firm performance. However, the ability to adopt such process innovations also varies depending on prior adoption of digital technologies and capabilities, which tends to be higher among larger firms (Riom and Valero, 2020[125]). Another survey of 247 organisations worldwide conducted in April and May 2020 reports that 52% of them pointed to the acceleration of digitisation as the most significant change to their innovation activity (Kanesarajah and White, 2020[124]).

As a result of business and consumer demand, firms providing digital products that help in the context of social distancing have seen a massive increase in demand, and have rapidly reacted by providing product updates (or add-ins) to improve the user experience. These digital innovations have some advantages – for instance they are often cheaper than their physical equivalents and require no travel, commuting or waiting time to use them. Thus for some users, the shift may become permanent. The increase in the number of USPTO patent applications of technologies that support work from home registered between January and May 2020 illustrates that innovators have responded to the increase in demand for these types of technologies (Figure 9) (Bloom, Davis and Zhestkova, 2020[133]).

Figure 9. USPTO patent applications filings that support work from home technologies, January 2010-May 2020

Share of monthly patent application filings to USPTO



Source: Bloom, Davis and Zhestkova (2020[133]).

The crisis has also stimulated experimentation with the deployment (often in pilot projects) of advanced technology applications by large digital technology firms. Alibaba, a Chinese e-commerce giant, is rolling out autonomous delivery systems. Pony.ai, a Chinese autonomous vehicle start-up, repurposed its fleet and launched a self-driving delivery service in Irvine, California (Shepherd, 2020[134]). Google deployed Wing drones to deliver medicines and other needs in rural Virginia. The service had been running a test programme since October 2019, and saw a rapid increase in requests for deliveries since the virus outbreak began (Block, 2020[135]). ZMP, a Japanese producer of robots, created an autonomous disinfection robot to help large building managers deal with COVID-19, and began trials of its autonomous delivery robots in Tokyo in the summer of 2020, much earlier than expected (The Economist, 2020[136]). A wide range of other industry 4.0 technologies has been deployed to respond to new needs during the pandemic (see overview in Javaid et al. (2020[137]).

The rapid uptake of digital tools by businesses as well as the larger-scale deployment of digital and data-driven innovations is expected to increase the demand for tech talent and workers with different levels of digital skills. Topcoder, an on-demand tech talent platform, already saw an increase in activity since the start of the COVID-19 crisis (Winsor, 2020[138]).

(6) Impacts on innovative entrepreneurship and slowdown in knowledge exchanges

With the exception of those directly responding to emerging market needs (e.g. provision of digital products), entrepreneurs may not have entered the market in 2020, and decided to wait until demand has recovered. Firm creation dropped significantly across many countries in March and April 2020 (Calvino, Criscuolo and Verlhac, 2020[139]). Data from France and the United Kingdom show that in both countries firm creation dropped by 25% and 23% respectively in March 2020 compared to March 2019, while weekly Business Formation Statistics from the US Census Bureau suggest a 20% decline year-on-year in March/April 2020[7] (Prashar et al., 2020[140]; Insee, 2020[141]; US Census Bureau, 2020[142]).

Interestingly, experimental evidence covering a sample of firms in the United States based on US Census Bureau data shows that the initial shock of the first COVID-19 wave in terms of business entry was short-lived, with a rapid rebound and a surge in business applications for start-ups as of July 2020 compared to the same period in 2019. During the 2008-09 crisis, business applications sharply declined (Figure 10). Data also show that non-store retailers – notably Internet sales – accounted for 33% of the surge in new business applications in 2020 relative to 2019. The sector had only accounted for 9% of applications in 2019 (US Census Bureau, 2020[4]). This suggests that the crisis may have encouraged entrepreneurship in some areas experiencing increased demand (e.g. in the digital sector). The UK Office of National Statistics also reported that the number of business creations in that country in the third quarter of 2020 was slightly higher than in the same period in 2019, following a small fall in the second quarter of 2020 (Office for National Statistics, 2020[143]).

Figure 10. Experimental evidence on cumulative differences in new business applications for likely employer start-ups, United States

Note: Weeks 1-52 for 2008-2007 difference; weeks 1-48 for 2020-2019 difference
Source: Tabulations from Dinlersoz, Dunne, Haltiwanger and Penciakova (2020[144])

While positive, this may be a momentary phenomenon only in view of future uncertainties and the fact that some business creation may relate to those affected by unemployment temporarily opting for private business activities. In the United States, stimulus packages focusing on protecting people's incomes instead of jobs may have also contributed to this trend (The Economist, 2020[145]). Monitoring the evolution of these data and analysis of sectoral breakdowns will help clarify changes.

As to bankruptcies, differently from the 2008-09 global financial crisis, evidence across several countries shows that the number of insolvencies was relatively stable (e.g. in the United States) or even dropped during the first three quarters of 2020, reaching lower levels than in the fourth quarter of 2019 (e.g. in France, Germany, Spain and the United Kingdom) (Claeys, Hoffmann and Wolff, 2021[146]). This, however, is largely the result of policy support provided to businesses in response to COVID-19, but also of temporary legal changes implemented in 2020 to bankruptcy rules, aimed at avoiding the liquidation of viable firms and the ripple effects this would create for the economy (in terms of increased unemployment, lower labour tax income, lower household consumption, etc.). While these measures prevented large increases in unemployment and enabled a partial economic rebound during the third quarter of 2020, corporate debt levels continued to rise, which could lead to increases in insolvencies once the temporary business support measures are lifted (Claeys, Hoffmann and Wolff, 2021[146]). While bankruptcies were often avoided, smaller and younger firms faced severe liquidity constraints as the COVID-19 crisis hit (Prashar et al., 2020[140]). Experimental data for the United States also finds small firms in industries most sensitive to social distancing were affected by closures (Crane et al., 2020[147]).

Obstacles to knowledge exchange that arise with “social distancing” are expected to affect innovative entrepreneurship and innovation negatively. Haskel and Westlake (2020[148]) hypothesise that the loss in knowledge exchange that inhibited clusters and “agglomeration effects” (the economic advantage of big dynamic cities) from operating reduces intangible capital formation in the short term and augurs negative impacts for the future. The missed opportunities for exchange also likely hampered new collaborations for innovation, including industry-science collaborations and the business activities these would have resulted in.

However, as discussed above, the COVID-19 crisis – similarly to previous ones – also offers opportunities for innovative start-ups and businesses. Companies such as Dropbox, Uber, Airbnb, Slack and Groupon were founded during or after the 2008-09 financial crises, and Alibaba’s Taobao was founded in 2003 during the SARS outbreak in China (OECD, 2020[149]).

2.3. Unequal effects of the COVID-19 crisis across STI actors

In 2020, the pandemic and subsequent economic crisis affected all actors in STI systems in practically all countries – but impacts differed across individuals, regions, sectors, firms, universities and research institutions. The crisis may also have affected stages of the innovation cycle differently (i.e. from fundamental research to applied research, development and the market launch of innovations). Paunov and Planes-Satorra (2021[5]) provide a more extensive discussion on the potential longer-term impacts of the crisis on the generation of disparities in STI systems.

(1) Unequal effects in the STI labour force

At the individual level, those in more vulnerable positions were hit hardest, including students from disadvantaged backgrounds (who may drop out of higher education and thus not integrate into the high-skilled workforce in the future), research students in their final year of studies (who may find it more challenging to find employment), and those with temporary appointments (who may see their contracts not renewed due to the reduction in financial resources in their institutions). Entrepreneurs who saw their income sources drop also face important challenges to continuing operations.

Early-career researchers faced major uncertainties. By October 2020 more than half of the scientists who participated in the OECD Science Flash Survey 2020 expected the crisis to negatively affect their job security and career opportunities (based on 2 600 responses from 94 countries) (OECD, 2020[150]). Getting a foot in the door of industry research was also more difficult in the early phase of the pandemic. Evidence from the United States suggests that firms significantly cut back on postings for high-skill jobs in March and April 2020 (Campello, Kankanhalli and Muthukrishnan, 2020[151]).

Virtual environments allowed maintaining connections with existing networks, but hampered the creation of new ones. The COVID-19 shock has generally helped well-known researchers but challenged early-career researchers to position themselves in the field. The need for swift solutions and the opportunities for virtual events to draw more on “superstars” led to fewer opportunities for less famous researchers to express their views, leading to the even greater dominance of those singled out as superstars in respective networks.

Women researchers (particularly in early career stages) were also more affected by lockdown measures of the first COVID-19 wave than their male peers, as they spent more time on childcare and elderly care duties (OECD, 2020[152]) (Minello, 2020[153]). A survey conducted in April 2020 gathering responses from 5 535 US- and Europe-based faculty or principal investigators across all disciplines found that female scientists, and especially those with young children, experienced a substantial decline in time devoted to research (Myers et al., 2020[154]). Another survey of 3 345 academics in Brazil conducted in April and May 2020 found that women researchers (especially black women and mothers) experienced the greatest reduction in productivity, as measured by their ability to submit research papers and meet deadlines (Staniscuaski et al., 2020[155]). An analysis of around 300 000 preprints and registered reports in March and April 2020 found that women’s research production significantly declined (compared with both the preceding two months and the same two months of 2019). The impact was more pronounced among early-career researchers (Vincent-Lamarre, Sugimoto and Larivière, 2020[156]). This may increase gender disparities in research careers if social distancing measures remain in place for a longer period (OECD, 2020[152]) (Minello, 2020[153]).

Women were also less engaged in COVID-19-related research. A study of working papers in economics finds that the proportion of female researchers (particularly in early and mid-career positions) engaged in research related to the pandemic between January and April 2020 was significantly lower (on average 12% of the total number of authors) than their average engagement (21%, considering the four-month average between 2015 and 2019) (Amano-Patiño et al., 2020[157]). The underrepresentation of women in COVID-19 research not only may affect research careers but also may mean that less research on the COVID-19-related challenges faced by women is addressed (Pinho-Gomes et al., 2020[158]).

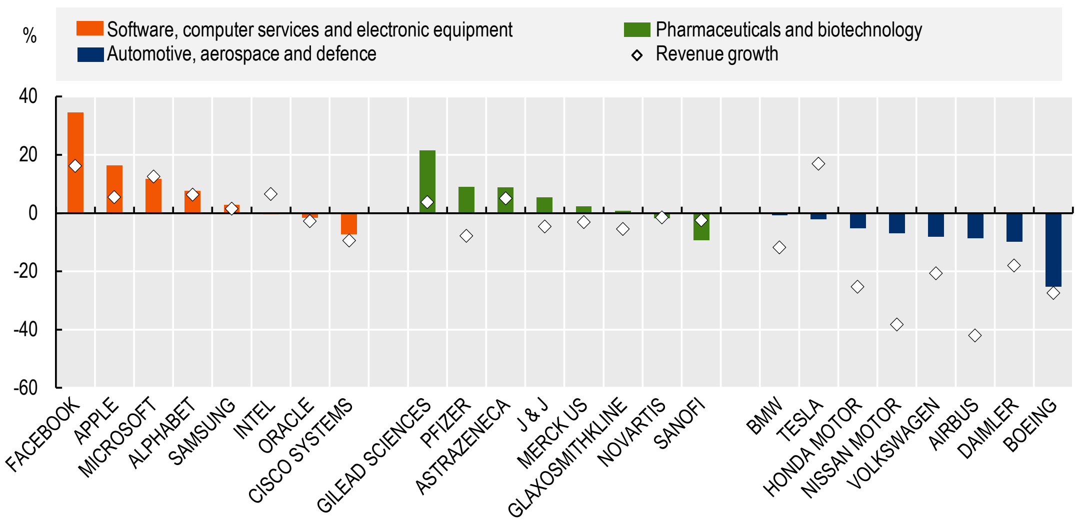
(2) Sectoral and firm-level differences

While COVID-19 reduced research and innovation investments across many businesses in 2020 (as pointed out in Section 2.2 above), the crisis had different impacts across sectors that themselves widely differ in terms of R&D intensity. The digital sector thrived in 2020 since, as discussed above, demand for many digital services increased with lockdown and social distancing restrictions. For instance, Amazon had revenues of USD 75.4 billion in the first quarter of 2020 (more than USD 33 million per hour), boosted by a surge in online ordering from customers locked down at home (an increase in sales of 26% compared to the same period in 2019) (Rushe and Sainato, 2020[159]). Google’s Alphabet saw sales rise by 13% in the first quarter of 2020 compared with the same period last year. This led to increased R&D investments in the sector, already among the most R&D-intensive before the crisis (Figure 11). Data based on Pitchbook suggest that in the United Kingdom the demand boost also resulted in improved angel and VC funding opportunities for those sectors. In April 2020, digital technology sectors (especially firms in the food tech, digital health and cybersecurity areas) received more

VC funding compared to the 2018/19 averages, while other sectors saw immediate decreases (e.g. biotechnology, FinTech, clean technologies and manufacturing) (Ipsos MORI, 2020[122]).

Figure 11. Reported R&D expense and revenue growth, selected R&D companies, April to September 2020

Percentage change with April to September 2019



Note: R&D growth rates are in nominal terms and measured between April to September 2019 and April to September 2020. The companies presented are a selection of the world's top R&D investors within different Industry Classification Benchmark (ICB) sector aggregates, based on the list in the 2019 EU Industrial R&D Investment Scoreboard, a ranking of companies according to their R&D expenses in 2018. Firms selected in this chart are publicly listed companies only for whom interim reports are available and include explicit R&D figures. Companies reporting broader categories such as "technology and content" are therefore excluded. Company reports of R&D expense need not coincide with R&D expenditures as covered in official R&D statistics compiled according to the Frascati Manual. For companies presenting their financial results in compliance with the International Financial Reporting Standards (IFRS), development costs are capitalised and consequently excluded from the R&D item in income statements. These costs are included in the R&D figures presented here, while amortisation of capitalised development expenditures are conversely excluded when the information is available. For companies following the United States Generally Accepted Accounting Principles (US GAAP), development costs are expensed as incurred (except for software development expenses under specific conditions) and figures are reported as provided. Data refer to the 6-month period from the beginning of April to the end of September, except for Cisco (May to October) and Oracle (March to August). For Astrazeneca, GlaxoSmithKline and Novartis, R&D figures are based on core results (excluding amortisation and impairment of intangible assets) rather than IFRS results.
Source: OECD (2021[6]), based on published quarterly business financial reports, December 2020.

This, however, is not to say that all digital companies were left unaffected by the crisis. A survey of Israeli technology start-ups with less than 50 employees found 19% of software and communication companies had shed employment as a result of COVID-19 by May 2020 (Solomon, 2020[119]). For platform-based firms belonging to the "sharing economy" and linked to travelling and mobility the shock has been severe, as is the case for many traditional service sectors, due to restricted mobility and "social distancing" measures implemented during the pandemic. In May 2020, Airbnb, the largest peer-to-peer platform for accommodation rental, announced it would lay off roughly 25% of its staff (1 900 people). Uber and Lyft, the two largest ride-sharing firms, also announced layoffs of around 14% and 17% of their global workforce (3 700 and 982 people, respectively) (Paul, 2020[160]).

Within the service sectors, the tourism, travel and leisure industries, as well as sectors requiring contact between consumers and service providers (e.g. hairdressers, retailers) were among the most affected by restrictions on movement and social distancing. The impact of these on R&D is likely to be minor, as the average company's R&D investment in these sectors is low.

More R&D-intensive activities were also severely affected, including manufacturing sectors with long global supply chains (e.g. automotive, aerospace, electronics), as well as sectors producing durable and investment products, as demand for such products slows during downturns.

At the firm level, SMEs especially have been affected by the crisis – they tend to be more vulnerable to liquidity constraints in a context of decreased demand, and are relatively less agile than large firms in adopting digital technologies or other innovations to adjust their activities to the new landscape.

(3) Territorial differences

The differences in effects across sectors influenced differences in the intensity of the shock at regional levels (Bailey et al., 2020[161]). Regions highly specialised in the tourism sector are among the most badly hit by the crisis, but are not the only ones (Gössling, Scott and Hall, 2020[162]; OECD, 2020[163]). Those specialised in aviation, automotive and other manufacturing activities were also particularly affected during the first months of the crisis. An analysis exploring the level of vulnerability of UK cities to the crisis conducted in April 2020 found that those with high shares of employees in the aviation and automotive sectors were the most vulnerable (Enenkel, 2020[164]). Regional variation in the share of jobs that can potentially be performed remotely also provide an indication of different impacts of confinement and other social distancing measures on disruptions to local economies (OECD, 2020[165]). Another factor leading to unequal impacts are local outbreaks of COVID-19, which resulted in particularly severe lockdown measures in some regions and cities.

The pandemic also risks widening disparities at global level. World Bank estimates suggest that the COVID-19 crisis pushed between 88 and 115 million people into extreme poverty in 2020, with the largest share of "new poor" in developing countries – particularly in South Asia, followed by Sub-Saharan Africa (Lakner et al., 2020[166]). Many of these low-income countries were already in debt distress before the pandemic, making it harder for them to support the most vulnerable in a context of global turndown (Blake and Wadhwa, 2020[167]). The crisis could slow down or even reverse recent advances in poverty reduction and economic development in low-income countries, possibly hindering capacity building efforts and delaying their integration in international research and innovation networks.

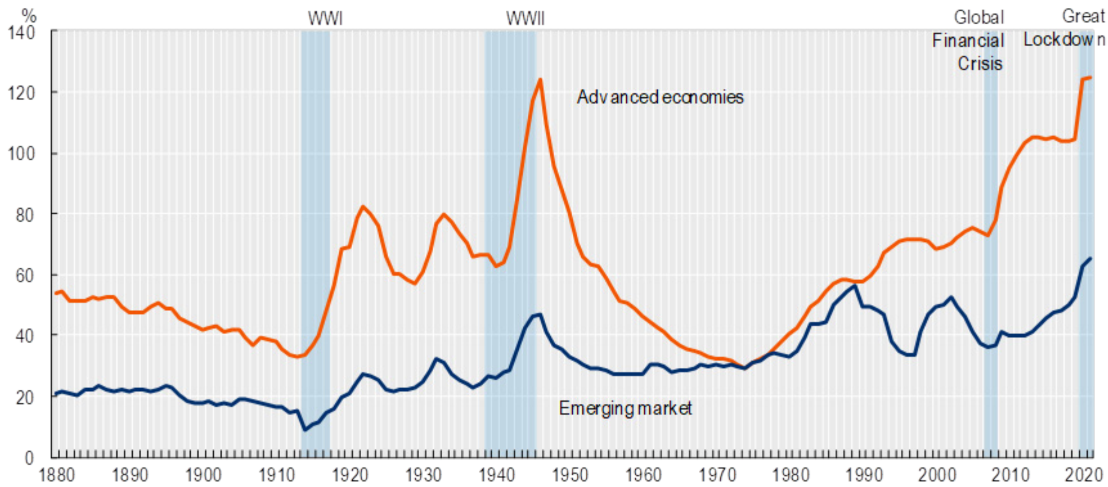
2.4. Policy measures implemented to support STI actors affected by the crisis

The immediate STI policy response to the pandemic impacts suffered focused on keeping innovative businesses afloat and helping researchers and research institutions quickly adapt to the new context. These were often part of wider stimulus packages aimed to boost the economy that directly or indirectly also support STI actors, such as the Coronavirus Aid, Relief, and Economic Security (CARES) Act in the United States (March 2020), the Korean New Deal (July 2020) and the France Relaunch Plan (September 2020). The scale and speed of fiscal support provided by many countries is exceptional, even when compared to that provided during the 2008-09 financial crisis, reaching historically high levels of public debt (Figure 12) (IMF, 2020[168]). In the United

States, the fiscal response (based on legislation enacted as of July 2020) is estimated to cost the federal government about USD 2.5 trillion over the next five years – above the USD 1.8 trillion of fiscal stimulus and other economic support enacted between 2008 and 2012 in response to the financial crisis (Committee for a Responsible Federal Budget, 2020[169]).

Figure 12. Historical patterns of general government debt

Percent of GDP



Note: The aggregate public-debt-to-GDP series for advanced economies and emerging market economies is based on a constant sample of 25 and 27 countries, respectively, weighted by GDP in purchasing power parity terms.
Source: IMF (2020[170])

The extent to which support reached businesses was substantive. Recent enterprise surveys conducted by the World Bank reflect the scale of government interventions to protect incomes, jobs and firms in most OECD countries: by June 2020, around 57% of firms in Italy had received or expected to receive government support to face the crisis. Shares amounted to around 72% of firms in Greece, Poland and Slovenia. Financial capacities to provide such support are much more restricted in the case of middle- and low-income countries. Responses to the World Bank's enterprise survey shows, for instance, that only 11% of firms in Honduras received government support to face the crisis. Shares were 8% in Chad, 15% in Niger, 26% in Guatemala and 28% in Morocco. Support in those countries tends to be directed mainly to large firms according to surveys conducted between June and August 2020 (World Bank Group, 2020[171]).

Immediate policy measures to address negative impacts on STI included those mentioned in the following paragraphs.

Flexibilities for existing beneficiaries of research and innovation programmes were rapidly introduced in most countries, and application deadlines were postponed. The pandemic affected the ability of existing recipients of R&D loans or grants to deliver their results on time, and that of those preparing proposals to have them ready by the deadlines. In response, the EU postponed application deadlines for most calls to give more time to applicants to prepare their proposals. The Research Council of Norway also released a range of measures and principles to assist grant holders and applicants to new projects to deal with the challenges. Similar flexibilities were introduced by most research funding bodies, such as the Australian Research Council and the German Research Foundation (Matthews, 2020[172]). In the Netherlands, the repayment of Innovation Credits provided by the Dutch Enterprise Agency to innovative SMEs could be delayed for six months.

Support was provided to *help higher education institutions and researchers cope with short-term challenges*. These included helping higher education institutions (HEIs) provide tools and training to academic staff, enabling them to effectively perform their teaching activities on line (e.g. by making the best use of tools available, implementing alternative interaction and assessment methods), and strengthening researchers' digital skills (e.g. in using online collaborative platforms). Immediate measures were also implemented to reassure students (from undergraduates to PhD candidates) and researchers (in particular early-career researchers with fixed-term or project-based contracts) about the continuity of their programmes and/or funding. For instance, UK Research and Innovation provided grant extensions of up to six months for UKRI-funded PhD students in their final year, whose studies had been disrupted by COVID-19. The German Federal Ministry of Research and Innovation made an additional EUR 100 million available for local student emergency funds to help students facing acute hardship. Many universities with well-established online programmes also made their training materials freely available, which additionally offered the advantages of scaling up online education compared to its offline alternative.

Measures were also adopted to *protect research jobs and projects impacted by the pandemic*. For instance, in May 2020 Canada announced CAD 450 million (USD 341.6 million) in funding was to be delivered as block grants for universities and health research institutions to retain research staff, keep essential research activities running during the pandemic, and help institutions ramp research back up once physical distance measures are lifted. In view of expected income losses caused by a decline in international students, the United Kingdom launched a GBP 280 million (USD 360.7 million) scheme that provides low interest loans to universities to support researchers' salaries and other costs such as laboratory equipment and fieldwork, as well as direct funding to maintain R&D projects.

Regarding business support, initiatives were introduced in many countries to *facilitate access to funding for entrepreneurs and innovative firms to mitigate their liquidity problems*. The support can take different forms, such as loans, grants and repayable advances. For instance, in late March 2020 France launched an Emergency Start-up Relief Plan of EUR 4 billion (USD 4.75 billion), which includes the provision of state-guaranteed cash-flow loans; cash advances through the fast-tracked repayment of corporate tax claims that are refundable in 2020 (including the 2019 R&D tax credit); and early payments of the PIA (Investments for the Future Programme) Innovation Grants. In April 2020, the United Kingdom launched a GBP 1.25 billion (USD 1.6 billion) package to support innovative firms hit by the pandemic. This includes a GBP 500 million investment fund for high-growth companies – made up of funding from government and the private sector – as well as GBP 750 million of grants and loans for SMEs focusing on R&D (GOV.UK, 2020[173]). Germany launched a EUR 2 billion (USD 2.4 billion) package to expand venture capital financing to support start-ups during the crisis (BMWi, 2020[174]), and Israel launched a NIS 2 billion (USD 580 million) Rescue Plan for the High-Tech Industry. The plan has allowed an increase in loans granted by the Innovation Authority, and offers large-scale debt financing to high-tech companies with significant assets (IP, funding, R&D) but facing cash flow difficulties. Most countries provide additional support to SMEs more generally, which is explored in detail in OECD (2020[175]).

Support for innovative businesses – particularly SMEs and start-ups – to adapt to the COVID-19 situation was provided in some countries, to help mitigate the short-term negative impacts. These can include supporting the use of online selling tools or adjusting production facilities to respond to new market demands. For instance, Enterprise Ireland provides Lean Business Continuity Vouchers of up to EUR 2 500 (USD 3 200) for companies to acquire training or advisory support related to the continued operation of their businesses during the pandemic. It also offers Business Process Improvement Grants, which includes support to strengthen businesses' use of the Internet as an effective channel for business development.

3. Debates about STI policy actions in relation to COVID-19 in 2020

The public health risks posed by COVID-19 and the high socio-economic costs of the resulting lockdown and social distancing measures put STI policy actions under scrutiny. This section presents a number of debates about STI policy responses in relation to the COVID-19 crisis in 2020.

3.1. Were STI measures to address COVID-19-related challenges most efficiently provided?

A number of challenges emerged regarding the optimal allocation of STI funds to address the COVID-19 crisis, given the scale and speed of disbursement.

First, the large increase in funding and support for STI addressing COVID-19 raised risks of duplication and redundancies in research efforts. Costly redundancies can arise with research efforts that do not build on the current state of the art – which evolves quickly in the case of COVID-19. Indeed, there is a limited number of researchers with the necessary human capital to advance the frontier of knowledge in this specific area, and activities undertaken by researchers without the necessary capacities but attracted by financial opportunities could be wasted (Younes et al., 2020[176]). Redundancies could also arise from insufficient coordination and duplication of research efforts (see debate in Section 3.2 below).

Second, the speed at which results were needed challenged providing support to a diversity of researchers across different disciplines and with diverse research approaches. In an attempt to accelerate responses, there was the risk that most funding for STI would be allocated to well-known players in the field (e.g. large pharma and biotech firms, well-known researchers). Azoulay and Jones (2020[177]) argued in May 2020 that drastic increases in funding to support R&D for COVID-19 solutions going beyond the medical sciences and the established researchers could bring better solutions, as innovation often comes "from unexpected corners". Several approaches were adopted to solicit diverse solutions to COVID-19, including by setting up open competitions to generate ideas in the early phase of the COVID-19 challenge. Portals with the latest information on open funding opportunities were also created to reach more applicants (such as the database provided and updated in 2020 by Science Business[8]). Gradually support also extended to researchers across a wide range of disciplines.

Third, the rapid expansion of funding to address the COVID-19 pandemic and support the STI system in the context of crisis posed a challenge to ministries and funding agencies in charge of STI. These public bodies required more evaluation capacities to respond to the important increases in the number of submissions, particularly for grant-based support measures – submissions that in some cases could not be given as thorough a review by funding agencies. These bodies were in parallel tasked with identifying which parts of the STI system needed most support and how best to deliver such support. This was the more so challenging as agencies were also affected by lockdown measures. Providing the necessary institutional support for a smooth operation of those allocating the funding mattered.

3.2. Was national and international coordination on COVID-19 optimal?

The engagement of the scientific community in COVID-19 research, stimulated both by the need of urgently finding solutions to the pandemic and the availability of significant amounts of funding to support those activities, raised concerns about the possibility of duplication of efforts if these were not sufficiently coordinated both at national and international levels. At the same time, as stressed by Azoulay and Jones (2020[177]), multiple efforts aimed at addressing the same COVID-19 challenges increase the odds of successfully finding solutions. Often what may look like duplication is a different experiment that may make a difference.

A related concern was that the progress in research and innovation in this domain may not be sufficiently complementary, so that the contributions by public and private actors may not result in optimal efforts to address the diversity of COVID-19-related challenges. Competitions of the winner-take-all variety discourage more incremental innovations, as the main race is towards being the first with whatever solution. This challenge, however, did not prove an obstacle to vaccine development as advance guarantees led to large investments by the private sector (see discussion in Section 1.2 above). As a way to optimise research to address COVID-19, Azoulay and Jones (2020[177]) proposed a COVID-19 Defense Research Committee to channel efforts in the United States, echoing the famous National Defense Research Committee (NDRC) that the country launched in 1940 as a model. In April 2020, Korea established a Government-wide Support Team for COVID-19 Treatment and Vaccine Development, which paralleled some of the activities of the NRDC model. It brought together experts from government, academia, research institutes, hospitals and industry to coordinate national resources for the development of COVID-19 therapeutics and vaccines (Ministry of Science and ICT, 2020[178]).

The STI community engaged in efforts to improve the diffusion of research results that contributed to avoid duplication of efforts and enhance coordination, including by leveraging digital platforms and new tools. SciSight, for instance, is a visualisation tool that allows exploring a fast-evolving literature network on the pandemic posted on the COVID-19 Open Research Dataset (CORD-19). Ensuring that public institutions responsible for funding COVID-19 research activities had an accurate and real-time overview of ongoing efforts of research groups and most recent developments achieved was also critical in this context. To that end, the NIH established the COVID-19 Candidate and Technologies Portal to collect information on potential or available diagnostic, vaccine and other candidates or technologies to address COVID-19, supporting the development of an inventory of ongoing efforts that is used for planning purposes (NIH, 2020[179]). There was widespread agreement among experts that while there were many small studies that did not have sufficient power or coordination, overall there was an unprecedented degree of coordination across the large number of trials, studies, and developments launched at all levels: among countries, between companies, and between industry and universities.

At the international level, co-ordination and information-sharing mechanisms were mobilised since the start of the pandemic to co-ordinate global research efforts, as explored in Section 1.1 above. International actors engaged in co-ordinating R&D efforts included the World Health Organization (WHO), the Global Research Collaboration for

Infectious Disease Preparedness (GLOPID-R), the Coalition for Epidemic Preparedness and Innovation (CEPI), the Gates Foundation, and Wellcome Trust. These institutions were prominent voices in 2020 as global responses to the COVID-19 challenge were discussed. The international governance mechanisms will certainly be assessed in the aftermath of the crisis, in order to learn from what worked best and identify possible areas of improvement, so as to enhance preparedness to future possible international crises of similar or different nature. Paunov and Planes-Satorra (2021[5]) discuss how STI can contribute to build governance systems that are more resilient to future shocks, building on lessons from the COVID-19 pandemic.

3.3. Were the right conditions in place to ensure quick and fair access to COVID-19 vaccines?

With vaccines having become available but not in sufficient quantities, the issue of providing quick and fair access to the vaccine within and across countries was much debated. Important policy efforts were undertaken in 2020 to enhance the manufacturing capacity of vaccines once these would be available, and to raise funds to ensure access to the vaccines by developing countries. The effective organisation of vaccination campaigns was also an important objective to provide the conditions for quick and fair access to COVID-19 vaccines.

The key global instrument to provide access to vaccines worldwide is the COVAX Facility – a global pooled procurement mechanism for COVID-19 vaccines, created in 2020 by the World Health Organisation jointly with CEPI and the Global Alliance for Vaccines and Immunisation (Gavi, a public-private partnership for vaccine development). By December 2020, 98 high-income countries had joined the initiative and agreed to make upfront payments to the Facility. The initiative is complemented by the COVAX Advance Market Commitment (AMC), a financial instrument that collects voluntary donations to cover funding for vaccines for 92 low- and middle-income countries (Gavi, 2020[180]). By January 2021, COVAX had raised over USD 4 billion of the USD 6.8 billion funding target for 2021 (Nature, 2021[182]). With those resources, COVAX has invested in a portfolio of vaccine candidates and offered demand guarantees to vaccine manufacturers to secure access to at least 2 billion doses of vaccines by the end of 2021. The guarantees provide incentives and assurances for manufacturers to expand their production capacity so as to bring vaccines to the market faster (WHO, 2020[50]). As of December 2020, the COVAX Facility had secured 370 million doses of the AstraZeneca/Oxford vaccine candidate, 500 million doses of the Janssen vaccine candidate, and 200 million doses of the Sanofi/GSK vaccine candidate (Gavi, 2020[181]). Vaccines are to be delivered to the 190 participating and eligible countries, proportional to their populations, initially prioritising healthcare workers and vulnerable groups, so as to protect 20% of the population. Of the 2 billion doses of vaccines for to be secured by the Facility in 2021, at least 1.3 billion would be delivered to the 92 low- and middle-income economies (Gavi, 2020[181]). For many of these countries access to vaccines may largely depend on the COVAX AMC (Oxfam International, 2020[183]).

High-income countries and some middle-income countries (such as Brazil, India, Indonesia, Malaysia, Thailand and Vietnam) also signed bilateral advanced purchase agreements with vaccine manufacturers (Dyer, 2020[183]) (The Economist, 2020[49]). By mid-August, the United States had pre-ordered 800 million doses of 6 vaccines in development, and the United Kingdom had purchased 340 million doses (Callaway, 2020[184]). The EU pre-ordered millions of doses on behalf of its Member States, following principles established in the EU Strategy for COVID-19 vaccines, approved in June 2020 (European Commission, 2020[185]).

By the end of January 2021 most high-income countries and some upper-middle income economies (including Brazil, China, India, Mexico and Turkey) had started vaccination campaigns with important differences in the rollout. According to Our World in Data, by 11 January 2021 Israel had administered 20.9 vaccination doses per 100 people[9]; the United States, Denmark and the United Kingdom had administered around 2 doses per 100 people. Figures were lower in other countries such as Spain (0.6) and France (0.12) (Our World in Data, 2021[186]). In January 2021 major challenges to roll out vaccination programmes more widely included organising the large-scale vaccination campaigns effectively and the insufficient supply of vaccines (Nature, 2021[182]).

3.4. Were science advisory and communication processes as effective as possible?

In a context of incomplete and rapidly evolving evidence as experienced during the course of 2020 with the COVID-19 pandemic, scientific advice processes were essential to inform policy makers' emergency responses. These processes are organised differently across countries. In most cases, ad hoc scientific advisory committees, task forces or expert groups have been created (e.g. in Austria, Chile, France, Greece, Spain and Switzerland), while in others pre-existing institutional structures have been used to gather scientific advice (e.g. the Scientific Advisory Group for Emergencies in the United Kingdom). These structures often involved a variety of scientific institutions and experts from different disciplines to increase their legitimacy and ensure they are unbiased and rely on multiple sources of evidence.

One shortcoming of several advisory committees was that they were composed mostly of health experts (epidemiologists, virologists, public health experts) and only a few were multidisciplinary. A strong reliance on the most established scientific experts was also observed, particularly in the early phase of the COVID-19 pandemic. An example of a multidisciplinary committee is the Swiss National COVID-19 Science Task Force, which involves experts in clinical care, data and modelling, digital epidemiology, economics and ethics, among other disciplines (OECD, 2020[187]; OECD, 2020[188]). The lack of a multidisciplinary approach in advisory committees may have affected anticipating and taking measures to address the wider damages from lockdowns implemented when the COVID-19 shock first hit (e.g. negative impacts on mental health, exacerbation of gender and income inequalities, etc.).

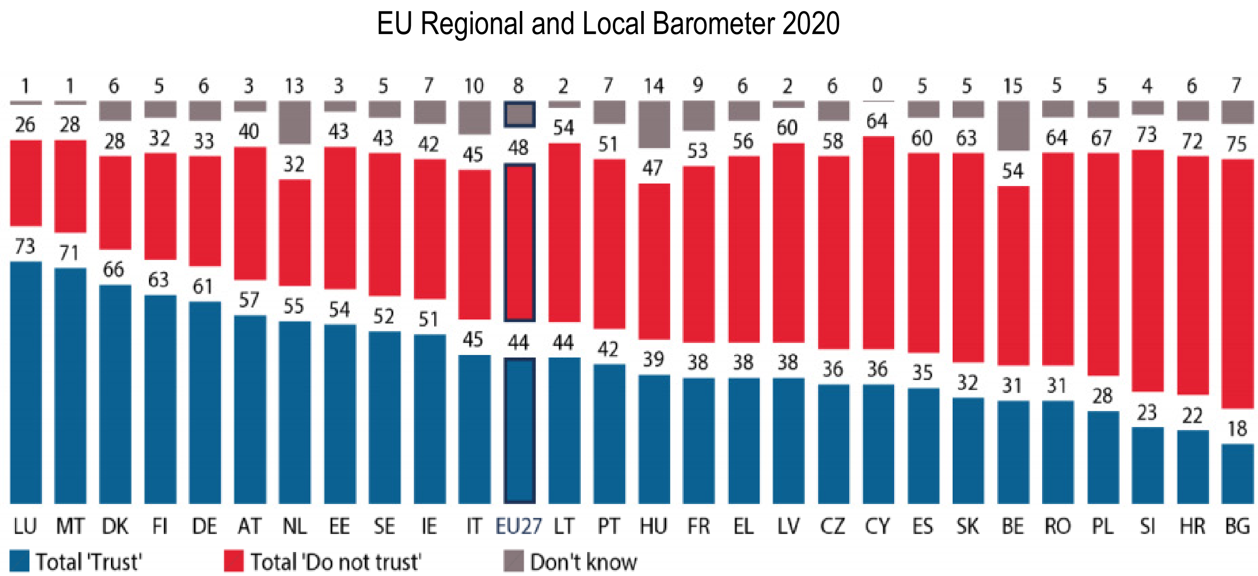
Another shortcoming has been the relatively low attention payed to international expertise. National responses between February and May 2020 were often primarily guided by the advice of national experts, with little co-ordination at international level (Soete, 2020[189]). Mobilisation at national level was possibly the most efficient way of providing rapid responses during the first weeks of the outbreak, but the shared experience of the pandemic provides many opportunities for joint research. A positive example in that direction is the Solidarity Trial of the WHO, which in October 2020 involved in trials almost 13 000 patients in 500 hospitals in 30 countries (WHO, 2020[190]). Some countries that have been exposed in the past to similar crises (e.g. SARS, MERS) can also have valuable lessons to share. For instance, the 2015 MERS crisis made Korea aware of the importance of timely and transparent health communication to the public during epidemics to maintain public trust in authorities and align the public risk perception with scientific evidence (Fung et al., 2015[191]).

The role of scientific advice in policy decisions has been of primary importance during the pandemic. Establishing the right dialogue with citizens is all the more important as the success of many "social confinement" measures implemented by governments – such as home confinement, social distancing and obligatory use of masks in public spaces – depends on them (OECD, 2020[192]; Betsch, Wieler and Habersaat, 2020[193]).

The high exposure of citizens to scientific communication during the COVID-19 crisis may affect individuals' levels of confidence in science and scientists in the longer run. On the one hand, science may be perceived as the only solution to the health crisis; on the other, the spread of misinformation on social media and the existence of uncertainties recognised by the scientific community can undermine public trust in scientific advice and policies. A recent study, based on data from a 2018 Wellcome Trust survey of more than 70 000 individuals in 160 countries and data on global epidemics since 1970, finds that individuals who have been exposed to epidemics in their countries at the age of 18 to 25 ("impressionable years") had significantly reduced confidence in scientists and the benefits of their work (Aksoy, Eichengreen and Saka, 2020[194]).

Levels of trust in government action in the longer run may also be closely tied to citizens' perception of the effectiveness and proportionality of measures implemented during the COVID-19 crisis. This assessment in turn also depends on scientific evidence on what constitutes the most effective measures to contain the spread of the virus compared to their socio-economic costs. In September 2020, the share of European citizens trusting local and regional public authorities to take the right decisions to overcome the socio-economic impacts of the crisis was 48% on average across the EU 27, according to the EU annual regional and local barometer (based on 26 381 responses from all EU countries). It was 44% for national governments (Figure 13) and 45% for the EU authorities.

Figure 13. Citizens' trust in national governments capacity to take the right measures to overcome the economic and social impact of the COVID-19 crisis



Note: The question of the survey was: please indicate how much you trust that your national government is taking, and will take in the future, the right measures to overcome the economic and social impact of the coronavirus crisis.

Source: European Committee of the Regions (2020[195]), based on a survey conducted online by Kantar, between 3 September and 17 September 2020, among 26 381 respondents in the 27 Member States.

Government decisions regarding confinement and other measures limiting the mobility and activity of citizens and businesses should always be informed by sound scientific advice. At the same time, it is the responsibility of governments to weigh up the trade-offs of each of those restrictions (e.g. the implications in terms of lost education opportunities and risks of widening disparities if schools close down; harm to mental health of extended isolation periods for those under quarantine), take balanced policy decisions, and clearly communicate them to the public. Experiences differ across countries, likely affecting the levels of trust of citizens in governments' capacity to implement effective recovery packages and steer the economy towards more sustainable, resilient and inclusive paths (Paunov and Planes-Satorra, 2021[5]).

Finally, the difficulties in containing the spread of the pandemic at the end of 2020 challenged relations between governments and citizens as further lockdown measures were implemented.

4. Conclusion

This paper provides an overview of the impacts of the COVID-19 crisis on science, technology and innovation systems in 2020. It also explores the nature of policy responses provided across countries, both to stimulate R&D and innovation activities to find solutions to the pandemic, and to support the STI actors (universities, research centres and innovative businesses) most affected by the crisis. Moreover, the report presents the debates that have been raised regarding the type and effectiveness of such responses. This includes questions regarding the effective allocation of support for STI in the time of COVID-19, the national and international coordination of research efforts, the mechanisms put in place to ensure global and fair access to vaccines, and the management of scientific advice and communication processes. These aspects should be further explored in the coming months (and possibly years), as data on the impacts of those activities become available for such analyses. Future work will be in position to leverage more and better data to improve this early assessment of the impacts of the crisis and policy responses, including providing responses to the debates around STI policy actions.

The impacts of the pandemic and the ensuing policy responses have changed or opened to question many pre-crisis practices. This includes the question of how STI systems should operate in the future – including the possible roles of open science and collaboration, the speed of policy responses, and digital work practices. The experience of the COVID-19 shock may change the very objective and mode of government practices. Not only inclusiveness and sustainability but also the building of more resilient STI systems may play more important roles in the future, so that the world can be better prepared for future crises. A more in-depth discussion around these aspects is provided in Paunov and Planes-Satorra (2021[5]), which explores the longer-term impacts of the COVID-19 crisis on STI as well as associated implications for the future of STI policy.

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Acronyms and abbreviations

ACT Accelerator	Access to COVID-19 Tools
ACTIV	Accelerating COVID-19 Therapeutic Interventions and Vaccines
AI	Artificial intelligence
COVAX AMC	COVAX Advance Market Commitment, Gavi
ANR	National Agency for Research, France
APS	American Physical Society
BMBF	Federal Ministry of Education and Research, Germany
CeADAR	National Centre for Applied Data Analytics and Machine Intelligence, Ireland
CEPI	Coalition for Epidemic Preparedness and Innovation
CSTP	Committee for Scientific and Technological Policy
C-TAP	COVID-19 Technology Access Pool, World Health Organization
DFG	German Research Foundation
EDPB	European Data Protection Board
EIC	European Innovation Council
FAIR	Findable, accessible, interoperable and reusable
FCT	Foundation for Science and Technology, Portugal
Gavi	Global Alliance for Vaccines and Immunisation
GLOPID-R	Global Research Collaboration for Infectious Disease Preparedness
HPC	High-performance computing
IATI	Israel Advanced Technologies Industries
IP	Intellectual property
KTI	Knowledge Transfer Ireland
MID	Ministry for Technological Innovation and Digitalisation, Italy
MIT	Massachusetts Institute of Technology
NAEC	New Approaches to Economic Challenges, OECD
NDRC	National Defense Research Committee, United States
NIH	National Institutes of Health
NRF	National Research Foundation, Korea
NSF	National Science Foundation, United States
PCT	Patent Cooperation Treaty
PIA	Investments for the Future Programme, France
RIETI	Research Institute of Economy, Trade and Industry, Japan
STI	Science, technology and innovation
TGA	Therapeutics Goods Administration, Australia
TIP	OECD Working Party on Technology and Innovation Policy
USPTO	United States Patent and Trademark Office
VC	Venture capital
WHO	World Health Organization
WIPO	World Intellectual Property Organization

Endnotes

[1] In October 2020 the CSTP organised two webinars: "STI Policy in times of uncertainty" (5 October 2020), and "Mobilising science in response to COVID-19" (21 October 2020).

[2] Between September and November 2020, the TIP Working Party organised a series of online talks: 1) "What role does technology play in building resilience to systemic shocks?" (2 October 2020); 2) "Learning about the future with scenarios: Innovation in a post-coronavirus world" (7 October 2020); 4) "How to co-create successfully? Developing lessons from the TIP co-creation case studies" (15 October); 4) "How is global innovation impacted by the COVID-19? Evidence of the Global Innovation Index (GII) 2020" (29 October); 5) "What's next for STI policies in times of COVID-19 and after? A perspective from Sweden" (12 November); 6) "Open data and AI analytics in times of COVID-19: A presentation of the CORD-19 initiative"(30 November). Find all information at: http://oe.cd/tipone.

[3] The priority areas were: 1) the virus' natural history, transmission and diagnostics; 2) animal and environmental research on the virus origin, and management measures at the human-animal interface; 3) epidemiological studies; 4) clinical management; 5) infection prevention and control; 6) candidate therapeutics R&D; 7) candidate vaccines R&D; 8) ethics considerations for research; 9) social sciences in the outbreak response.

[4] *JAMA*, *The Lancet* and *The New England Journal of Medicine* are excluded because of lack of appropriate data.

[5] Lockdown measures thus affected scientists working in different disciplines unevenly. An international survey conducted by Springer Nature and Digital Science from 24 May to 18 June found, based on responses from 3 436 researchers across different disciplines, that those most affected were chemistry, biology, medicine and materials science, while the lowest level of impact was reported in humanities and social sciences (Baynes and Hahnel, 2020[89]). Another survey based on responses from 4 535 faculty or principal investigators, conducted in April 2020, found that researchers in biochemistry, biology, chemistry and engineering were the most affected in terms of reduction of time devoted to research, while it increased for researchers in the fields of health, economics and mathematics (Myers et al., 2020[154]).

[6] Preliminary evidence suggests that in March and April 2020, there was a worldwide decrease of 65% and 79% respectively in the average number of new patients enrolling in clinical trials, year-over-year (Medidata, 2020[196]).

[7] Data cover weeks 10 to 15 (1 March to 11 April 2020) and comprises a subset of business defined by the US Census Bureau as "High propensity businesses", i.e. applications that have a high likelihood of turning into true employer businesses within eight quarters, based on underlying characteristics of the applicant.

[8] ScienceBusiness Database, Coronavirus Funding Opportunities, https://sciencebusiness.net/covid-19/funding-database.

[9] Figures refer to the number of COVID-19 vaccination doses administered per 100 people within a given population. This is counted as a single dose, and may not equal the total number of people vaccinated, depending on the specific dose regime (e.g. people that receive multiple doses).