1 COVID-19: A pivot point for science, technology and innovation?

The COVID-19 pandemic has called for science, technology and innovation (STI) to provide solutions. At the same time it poses major challenges for STI systems, and there remains uncertainty on its near-term and long-term impacts. This chapter outlines the STI policy responses to the COVID-19 shock and the effects of the crisis on STI systems. It offers a stylised framework for governments to systematically monitor the evolution of the crisis and its consequences from an STI policy perspective. It discusses a series of “critical pivot points”, where future developments could go in radically different directions. The chapter concludes by discussing how STI policy can best contribute to shaping those critical pivot points to support a transition towards more equitable, sustainable and resilient futures.

Key findings

- **Research and innovation systems have responded impressively to the pandemic**, underpinning much of the resiliency countries have shown. Both private and public actors in the STI system have provided solutions to the crisis, most visibly in the rapid development of vaccines, but also in the rollout of digital technologies that have helped lessen the pandemic's impact. COVID-19 has accelerated trends that were already underway, opening access to scientific publications, increasing the use of digital tools, enhancing international STI collaboration and spurring a variety of public-private partnerships.
- **The pandemic continues to pose major challenges for STI systems**, endangering key productive and innovation capabilities, especially in hard hit sectors. Important segments of the STI system have been severely affected, including a large share of small and medium-sized enterprises (SMEs), early-stage start-ups, young researchers still needing to make their mark, and women – who, on average, devoted more time to care duties at the expense of their STI activities during lockdown. In the short-term, governments should continue their support for science and innovation activities that aim to develop solutions to the pandemic and to mitigate its negative impacts, while paying attention to the uneven distributional effects of COVID-19.
- **Many uncertainties remain that will shape research and innovation systems, and the contributions these systems can make to solving societies' longer-term grand challenges**. The chapter discusses a series of "critical pivot points", where future developments could go in radically different directions. Monitoring these can provide an early warning system that alerts policy makers (and others) to possible future developments. It also allows decision makers to keep sight of alternative pathways and outcomes they could pursue, or want to avoid, thereby making STI policy more agile and resilient.

Introduction

The COVID-19 pandemic poses a global health threat and has resulted in the largest global economic crisis since the Second World War. In the absence of population immunity to the disease and effective treatments, extensive lockdowns and related sanitary and "social distancing" measures are needed, which involve a high socio-economic cost. In this context, much attention has been directed at science, technology and innovation (STI) to provide solutions quickly, even though the COVID-19 crisis has also severely affected STI activities. With ongoing uncertainty on the evolution of the pandemic, and massive government intervention to safeguard public health and the economy, the global economy faces several critical pivot points that will shape the longer-term impacts of the crisis. STI systems and policies have a role to play in shaping the directions of those critical pivot points.

The objective of this chapter is to synthesise the state of STI during the COVID-19 pandemic. It first presents how the STI system has engaged in finding solutions to the COVID-19 health challenge, and how the diverse actors of the STI system – industry, universities, public research institutes and the research workforce – were affected by the pandemic. Second, it provides a short overview of the types of STI policy measures implemented across the OECD area to respond to the crisis. Third, it discusses the key critical pivot points facing the global economy, their implications for STI, and how STI policy can best respond.

Both private and public actors in the STI system have engaged actively in providing solutions to the COVID-19 crisis. This has led to massive investments in research on vaccines and treatments, but also produced innovations to deal with the impacts of "social distancing" measures, such as improvements in digital tools to work remotely. A rapid surge in COVID-19-related research articles in the medical field and other disciplines was observed during the first months of the outbreak, and has been followed by a steady addition of research papers informing the scientific debate (see Chapter 2). Initiatives to facilitate data sharing and access to critical research infrastructures were also undertaken to speed up responses, along with new processes, such as hackathons, to solicit inputs and measures supporting effective collaborations. Nonetheless, as the world scrambles to find decisive solutions to COVID-19, it is debatable whether these collaborations have occurred on a sufficiently global scale, and whether funding has been sufficient and appropriately allocated.

With the sudden shock of the COVID-19 pandemic and its first wave, the operation of the STI system was severely affected, albeit with uneven impacts. Businesses, research institutes and universities saw their research and innovation activities severely disrupted by lockdowns and social distancing measures. Following the initial shock, several parts of the STI system – including venture capital (VC) funding, patenting and entrepreneurship, but also large research and development (R&D) investments by leading firms in the digital and health sectors – recovered quickly as governments lifted lockdown measures after the first wave of the pandemic. Many companies in the digital sector – already a leading R&D investor prior to the crisis – grew as the COVID-19 crisis hit, since digital tools proved essential to limit the costs of social distancing measures. The relatively quick recovery of parts of the STI system was also driven by the fact that aside from initial disruptions in global supply chains, a number of large companies were able to resume their activities and saw a return of demand after the lockdowns of the first wave of COVID-19 were lifted. Funding for innovation also kept up thanks to active government interventions and boosts to a number of firms by capital investors.

At the same time, important segments of the STI system were severely hit, including a large share of innovative small and medium-sized enterprises (SMEs), early-stage start-ups, young researchers still needing to make their mark, and women – who, on average, devoted more time to care duties at the expense of their STI activities during lockdown. The sectors most hit by the crisis – e.g. entertainment, tourism, retail and aviation – are among the smaller actors in terms of R&D-intensive technological innovation performance.

Early STI policy responses to the crisis strongly focused on providing funding for COVID-19-related research and innovation, with governments, foundations and industry raising several billion dollars to fund new vaccines and therapeutics. Governments also lent support to those STI actors most severely affected by the crisis. An impressive battery of fast-track policy measures were rolled out to mobilise the STI ecosystem to provide solutions to the pandemic, solicit inputs from diverse actors, facilitate co-operation and knowledge sharing, ease barriers that slow down innovation (e.g. through regulatory flexibilities and accelerated intellectual property examinations), and enhance international collaboration on addressing the global challenge. However, the ongoing uncertainty poses potentially longer-term challenges for STI to keep up as an engine of recovery.

The crisis also prompted government innovation, illustrated by the use of digital contact-tracing apps (though with mixed results), but also the use of real-time data analysis for policy making at levels not previously seen. Governments set up schemes to keep innovative businesses afloat (e.g. facilitating access to finance by innovative firms and start-ups), and help researchers and research institutes adapt to the new context (OECD, 2020[1]) Most countries are also preparing or have recently launched stimulus and recovery packages to boost the economy and, in particular, protect jobs that directly or indirectly support STI actors.

Looking forward, the COVID-19 pandemic presents a number of significant uncertainties for the future of STI. Besides the course of the pandemic itself, among those explored in this chapter are (1) the value society assigns to sustainability, inclusivity and resilience in shaping futures, but also to the role governments and STI should play in supporting those futures; (2) the pace and direction of the digital transformation, which influences both STI processes themselves and demands for innovation in the future; (3) social preferences on the importance of inclusive economic and societal outcomes, which may change fundamentally and affect the inclusiveness of innovation processes; and (4) changes in the international political economy – driven in part by the desire to reduce vulnerabilities in the future – which will shape the division of labour of STI systems at the national, (supranational) regional, and global levels.

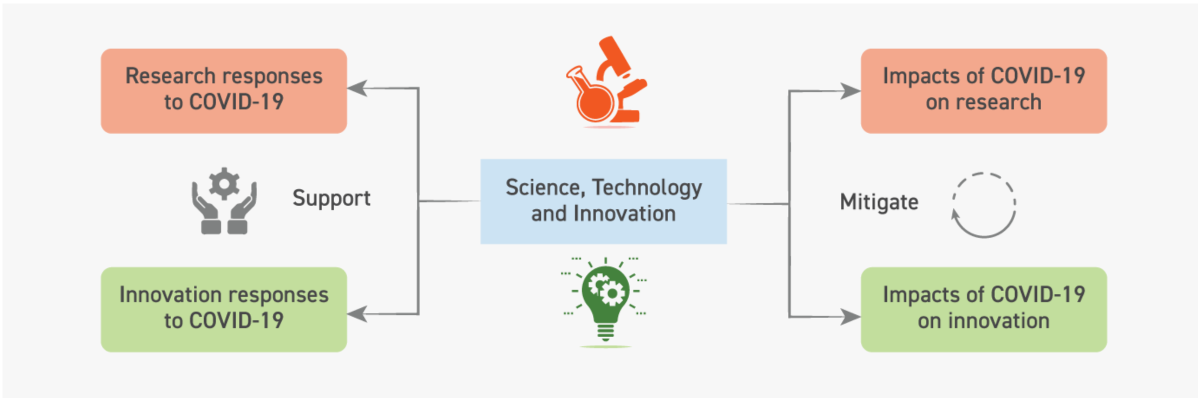
STI policies are affected by these uncertainties at the same time that they can contribute to shaping them. Policy can deploy STI to find solutions, manage effective dialogue between citizens and government bodies to handle the COVID-19 crisis (including confinement decisions and their trade-offs), deal with the potential distributional effects of COVID-19 on STI systems, and mobilise the responsiveness of STI systems. STI policies will also be influenced by the manner in which the COVID-19 crisis and these key uncertainties co-evolve, e.g. in terms of available funding for research and innovation, and the priorities governments and other actors pursue.

More extensive analysis of the issues discussed here is provided in two policy papers on the impacts on STI of the COVID-19 crisis between January 2020 and September 2020 (Paunov and Planes-Satorra, forthcoming[2]), and on its possible longer-term impacts and policy implications for STI (Paunov and Planes-Satorra, forthcoming[3])[1]. The analysis also leverages information on country policies collected through the OECD Survey on STI Policy Responses to COVID-19 (OECD, 2020[4]).

STI responses to the COVID-19 crisis and impacts on STI systems

The COVID-19 pandemic has set off a cascade of responses from – and impacts on – the STI ecosystem in many countries (Figure 1.1). This section explores the situation in public research sectors and the business community, highlighting not only the pivot to relevant research and scientific advice, but also the disruption to research activities and the asymmetric impacts on researchers and firms.

Figure 1.1. The roles of STI in the immediate crisis



Public research organisations and researchers' responses and impacts

Research activities that respond to COVID-19

Rapid deployment of research on solutions to COVID-19

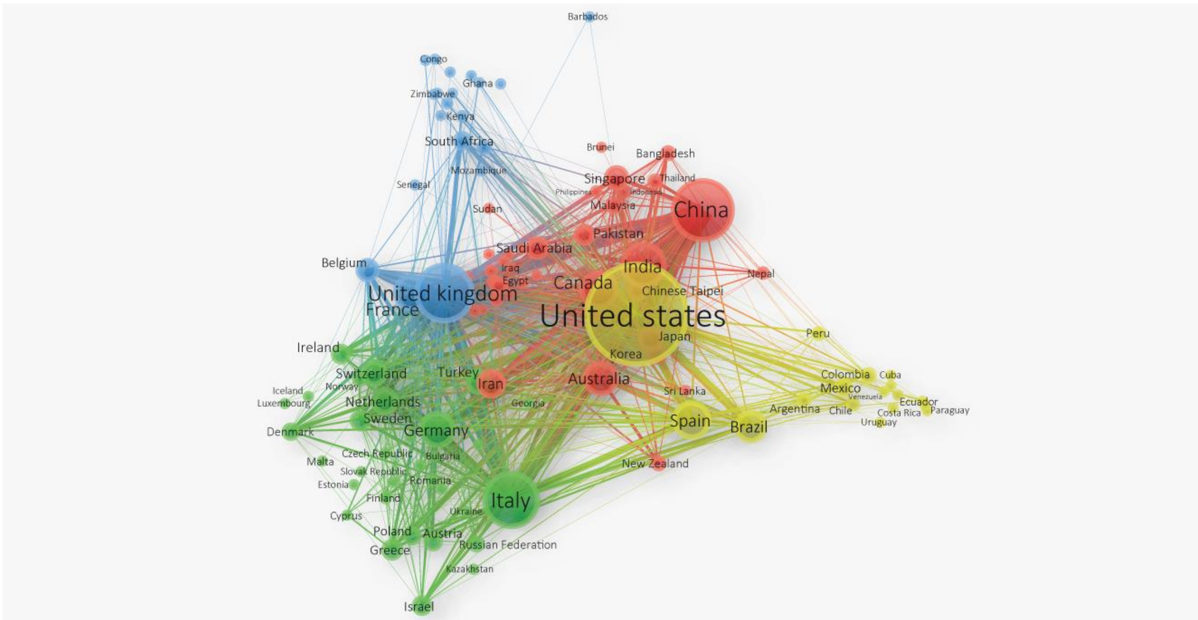
Universities, public research institutes, and pharmaceutical and biotech firms – sometimes in collaboration – have undertaken R&D to rapidly develop new treatments and vaccines for COVID-19. Several trackers provide real-time information on vaccine development, including the *New York Times* coronavirus vaccine tracker,[2] based on World Health Organization (WHO) data. Already by the end of May 2020, 131 vaccine candidates (10 in clinical evaluation) were under consideration. By early September 2020, the numbers had increased to 180 vaccine candidates, 35 of which were in clinical evaluation (WHO, 2020[5]). By mid-October 2020, the National Institute of Health's database in the United States showed that more than 3 600 trials on COVID-19 had been conducted or were still under way around the world (NIH, 2020[6]). The vast majority are clinical trials for drugs to treat COVID-19, around 30% of which are registered in the United States (Chapter 5). As 2020 drew to a close, the vaccination rollout had started in a first set of countries, providing cautious hope for an exit to the crisis, although reaching a critical mass of people will still take months and years.

The active engagement of the scientific community is also reflected in the explosion of scientific publications related to the virus. By mid-April 2020, more than 3 500 COVID-19-related articles had already 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 Center for Biotechnology Information (Bryan, Lemus and Marshall, 2020[7]). By the end of November 2020, articles related to COVID-19 on PubMed numbered around 75 000 (Chapter 2 provides a detailed breakdown of publications on COVID-19). Other evidence of the massive and rapid engagement comes from an international survey of researchers in different disciplines conducted by Springer Nature and Digital Science from 24 May to 18 June, which found that 43% of the 3 436 surveyed had already or were likely to repurpose their grants for COVID-19 research (Baynes and Hahnel, 2020[8]).

Figure 1.2 maps the country of origin of research on COVID-19 and shows that the United States and the People's Republic of China (hereafter, China) are among the two major contributors to COVID-19 publications on PubMed. They are also each other's main collaborating partner (see Chapter 5). Other research confirms this pattern, showing that the United States and China increased their levels of collaboration following the outbreak (compared to coronavirus research conducted prior to the COVID-19 pandemic) (Fry et al., 2020[9]). Other countries with high engagement in international research collaborations on COVID-19 include the United Kingdom, Germany, France, Italy, Australia, Canada and India.

Figure 1.2. 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 and OCTS-OEI calculations, based on U.S. National Institutes of Health PubMed data, https://pubmed.ncbi.nlm.nih.gov/ (accessed 30 November 2020).

StatLink https://doi.org/10.1787/888934223099

Provision of scientific advice to policy makers and the public

Countries have different standing systems for providing science advice to policy makers, supplemented by additional ad hoc mechanisms in times of crisis. While most OECD countries have relied on national expertise, many lesser-developed economies have been more reliant on international sources of advice, for example from the WHO. As the pandemic has evolved, the requirements for scientific advice have expanded across ministries and geographic scales – local, national and international.

Scientific evidence that is informing the policy response to COVID-19 remains incomplete and conditional; as more data are collected, the scientific understanding of COVID-19 changes. This dynamic situation has represented a challenge for the scientific community at a time when policy makers and the public have sought assurance and certainty. Scientific consensus continues to be difficult to achieve, and yet communicating uncertainties and alternative views can undermine trust in scientific advice and related policies (see Chapter 8).

In many countries, scientific experts have become national spokespersons, who are expected not only to provide scientific evidence, but also to justify policy actions. This has sometimes blurred the distinction between advisor and policy maker. With the second wave of COVID-19 infections, there exists intense public debate about the scientific data and information that help determine policy. Trust is critical to ensuring support and compliance with policy measures, such as obligatory wearing of masks and social distancing. In the longer term, trust will be important in ensuring solidarity and broad public support for interventions to ensure socio-economic recovery.

Open access to journal articles has reached unprecedented levels

An important change effected by the pandemic has been the greater speed in which scientific research results have been released, highlighting the role of open science. Many journals have accelerated their peer-review processes to ensure rapid dissemination. Based on data from 669 articles published in 14 medical journals during and prior to the current pandemic, a study finds that the time to publish had decreased by 49% on average, from 117 days to 60 days (Horbach, 2020[10]). Pre-prints (i.e. academic papers that have not yet been peer-reviewed or published) have become more common in the medical research field in a matter of weeks. Pre-prints allow increased speed of diffusion (also across scientific fields) and reaching a wider range of potential peers. Their rapid adoption is also illustrated by the high proportion of open-access documents published: OECD analysis of PubMed finds that the share of open-access research on COVID-19 was 76% (compared, for example, to 43% for Diabetes and 40% for Dementia publications over the same period – see Chapter 2).

Impacts of the COVID-19 crisis on the public research sector

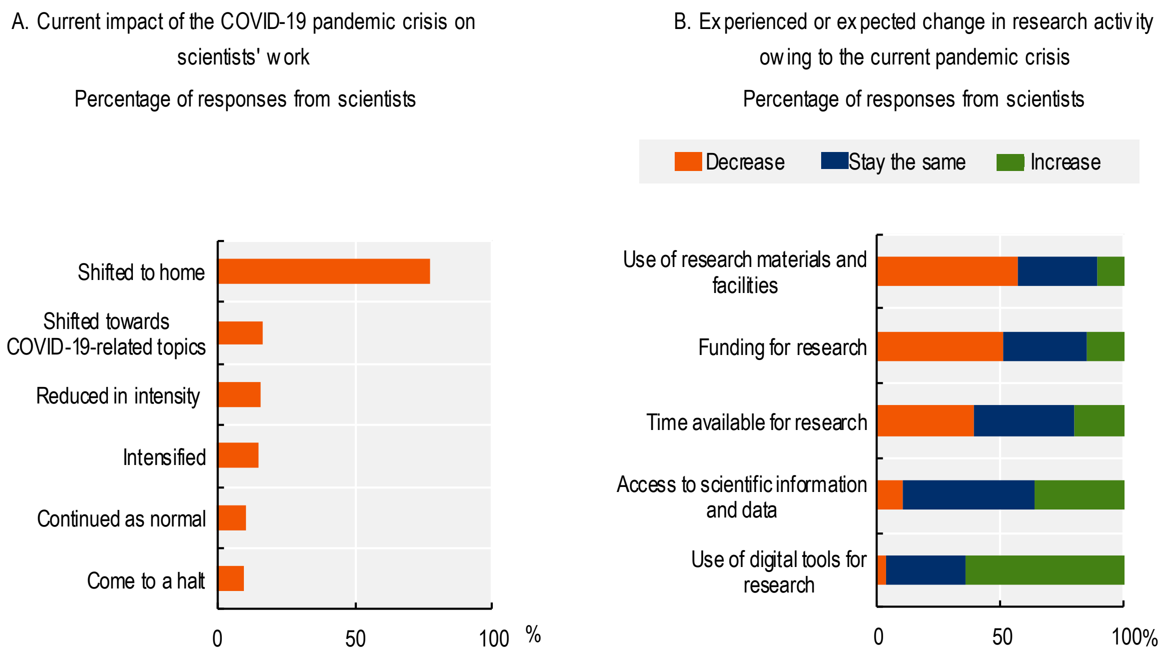
Limited access to research infrastructures and tools during lockdown

With the exception of activities directly addressing the COVID-19 health emergency and others considered essential to protect the public, research and innovation activities requiring physical access to laboratories and other research facilities, as well as those involving field work or clinical trials, were strongly disrupted by lockdown measures (World Bank, 2020[11]). This included activities where interruptions severely impede research delivery (e.g. long-term experiments where time-frequency observation is critical) and those requiring ongoing supervision for regulatory, safety or health requirements (e.g. caring for living specimens or research that uses hazardous materials)[3].

Where access restrictions applied, many researchers shifted to research activities that can be conducted from home (Stenvot, 2020[12]). A ResearchGate survey using data from 3 000 international researchers across academic fields suggested that nearly half of them replaced on-site activities with more focused writing, analysis, publishing and planning for future research during the first wave of the lockdown. In the absence of new research data, some also spent more time analysing older data sets that had not been explored previously (Research Gate, 2020[13]; Baynes and Hahnel, 2020[8]). Others donated their time and expertise to fight the coronavirus, repurposing their facilities and equipment to serve COVID-19 needs. For example, the Francis Crick Institute in London, a cancer research centre, has partly turned into a coronavirus-testing facility (Viglione, 2020[14]; Baker, 2020[15]).

Results from the OECD Science Flash Survey 2020[4] echo these findings, with more than three-quarters of scientists indicating they had shifted to working from home (Figure 1.3, Panel A). More than half experienced or expect a decrease in the use of research materials and facilities, and around 40% a fall in the time available for research. More than half also experienced or expect a decline in research funding (Figure 1.3, Panel B).

Figure 1.3. Impact of the COVID-19 crisis on scientists' work



Note: Panel A shows the percentage of responses from scientists to the statement, "In recent weeks and days, as the COVID-19 emergency intensified, your work has (i) Come to a halt; (ii) Continued as normal; (iii) Intensified; (iv) Reduced in intensity; (v) Shifted towards COVID-19-related topics; and (vi) Shifted to home". Panel B shows the percentage of responses from scientists to the question, "As a result of the current crisis, have you personally experienced or do you expect to experience a change in (i) Use of digital tools for research; (ii) Access to scientific information and data; (iii) Time available for research; (iv) Funding for research; and (v) Use of research materials and facilities?"
Source: OECD Science Flash Survey 2020, https://oecdsciencesurveys.github.io/2020flashsciencecovid/ (accessed 12 October 2020).

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The "COVID-isation" of research

The lockdown measures affected scientific disciplines unevenly by diverting research efforts towards COVID-19. Based on responses from 3 436 researchers, an international survey conducted by Springer Nature and Digital Science from 24 May to 18 June 2020 found that the disciplines most disrupted, e.g. due to lab closures, were chemistry, biology, medicine and materials science, while the humanities and social sciences reported the lowest impact (Baynes and Hahnel, 2020[8]). Based on responses from nearly 1 300 researchers, the OECD Science Flash Survey, launched in April 2020, found the lockdown had the highest disruption on immunology and microbiology, health professions, and pharmaceuticals, while physics and astronomy, and earth and planetary sciences, reported the least disruption.

The flip side to widespread engagement of the research community in designing solutions to COVID-19 is the risk of diverting research efforts away from non-COVID-19-related topics. The Cancer Research Institute, for instance, registered 958 stopped clinical trials due to COVID-19 from March to September 2020 (Cancer Research Institute, 2020[16]). This applies to the medical field, but also to other science fields (see Chapter 2). Madhukar Pai, Director of the McGill Global Health Programs, referred to this threat as the "COVID-isation" of research, which is leading researchers across disciplines to engage in such activities (Pai, 2020[17]).

Decline in income from research and tuition fees

Universities also face important short-term financial challenges resulting from the pandemic. Some students may defer or abandon their plans to engage in higher education programmes in 2020/21 (Jaschik, 2020[18]). Some may also abandon or postpone their plans to study abroad. Consequently, universities that rely heavily on student tuition fees, particularly those with an important share of international students, will suffer from reductions in income. This could also have an impact on research spending, as teaching income often cross-subsidises research activities. This could be accompanied by reductions in research funding (e.g. contract research income from firms) and other income-generating activities, such as accommodation and conferencing.

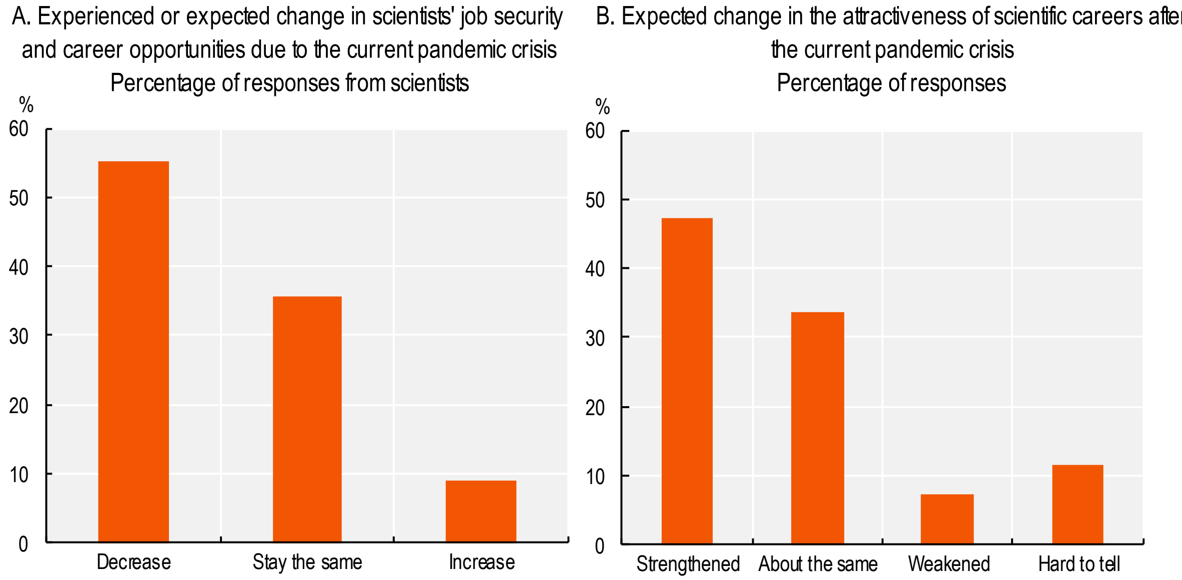
Effect of lockdown measures on researchers and successful adoption of digital substitutes

Severe restrictions to travel imposed by lockdown measures have interrupted the mobility of human resources in STI (e.g. visiting researchers, staff exchanges with industry). During the first months of the pandemic, many scientific events and conferences were postponed or cancelled, and uncertainty still prevails as to when they will fully resume. As substitutes, some of these conferences and events (including large flagship conferences) are increasingly organised digitally, sometimes registering very high attendance. For instance, the American Physical Society had over 7 000 registered participants for its April 2020 meeting held online, a significantly higher number than the 1 700 participants on average who would normally attend the in-person meeting (Castelvecchi, 2020[19]). Such a move has emphasised the advantages of digital conferences, particularly in terms of improved accessibility, reaching more diverse audiences, lower costs and reduction in the carbon footprint of travel. Nevertheless, virtual exchanges are not perfect substitutes for in-person conferences, which often result in collaborations and long-term trusted relationships, and also represent an opportunity for early-career researchers to find jobs and enhance the visibility of their work.

Negative impacts on young and female researchers

The limitations of virtual environments have favoured ongoing connections, but not the creation of new connections. They have also disadvantaged job starters, including early-career researchers with fixed-term contracts, who need to connect and share their work. More than half of the scientists who had responded to the OECD Science Flash Survey 2020 by October 2020 expected the crisis to negatively affect their job security and career opportunities (Figure 1.4, Panel A). Getting a foot in the door of industry research was also more difficult in the early phase of COVID-19. 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[20]). 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 ability of virtual events to draw more “star power”, have led to fewer opportunities for less well-known researchers to express their views, culminating in more dominance for those singled out as superstars in their respective networks (see Chapter 2).

Figure 1.4. Scientists' expectations for a research career in light of the COVID-19 crisis



Note: Panel A shows the percentage of responses by scientists to the question, "As a result of the current crisis, have you personally experienced or do you expect to experience a change in your job security and career opportunities?" Panel B shows the percentage of all responses to the question, "How do you expect the world of science to emerge out of the current crisis, in terms of attractiveness of scientific careers?"
Source: OECD Science Flash Survey 2020, https://oecdsciencesurveys.github.io/2020flashsciencecovid/ (accessed 1 October 2020).

StatLink https://doi.org/10.1787/888934223137

Women were also particularly affected, as they spent more time on childcare and elderly care during the lockdown of the first COVID-19 wave (OECD, 2020[21]; Minello, 2020[22]). An analysis of more than 300 000 pre-prints and registered reports finds that women's research production significantly declined in March and April 2020 compared to both the two preceding months and the same two months of 2019, with a disproportionate impact on early-career researchers (Vincent-Lamarre, Sugimoto and Larivière, 2020[23]). Another analysis based on publication data for working papers finds that although COVID-19 has spurred research in economics, the average share of female researchers (particularly in early and mid-career positions) engaged in research related to the pandemic is significantly lower (12% of the total number of authors) than their average engagement in other topics (21%). However, the study also finds that women have continued to work on their ongoing research, suggesting they have contributed less to the new literature on the economics of pandemics (Amano-Patiño et al., 2020[24]).

Despite this gloomy picture, respondents to the OECD Science Flash Survey 2020 were more sanguine about the attractiveness of scientific careers in the long run, with nearly half expecting it to increase (Figure 1.4, Panel B).

Mobilising business innovation

Business innovation activities in response to COVID-19

Aside from research conducted by the health industry – often in connection with public research organisations – industry has also moved to respond to COVID-19 challenges. A survey of R&D professionals and decision makers at 247 patenting companies showed that close to one-quarter (23%) of companies had repurposed their innovations in markets, such as internet services, communications, sanitation and healthcare/hospital services, even if this was not their primary industry (Kanesarajah and White, 2020[25]). An illustrative example of industry engagement is the strong increase in United States Patent and Trademark Office (USPTO) patent applications on technologies supporting working from home (WFH) between January and May 2020 (Bloom, Davis, and Zhestkova, 2020[26]).

Another phenomenon observed during the first months of the pandemic was the quick development of frugal innovations to remedy supply shortages in medical equipment and other emergency products (Harris et al., 2020[27]). In mid-March 2020, an Italian start-up reverse-engineered a 3D-printed version of a respirator valve and supplied 100 of those to Chiari hospital within a few days. Soon afterwards, the team engineered an emergency ventilator mask, modifying a snorkelling mask already available on the market from the French sporting goods retailer Decathlon (Isinnova, 2020[28]). Some firms in the automotive, aviation or 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.

Academic start-up companies also played an important role in answering the immediate needs posed by the COVID-19 health challenge. Zentech,[5] a biotechnology company founded in 2001 as a spin-off of the University of Liege, developed "QuickZen", an antibody testing kit intended for use by healthcare professionals. AdaptVac,[6] a joint venture between ExpreS2ion Biotech and the University of Copenhagen spinout NextGen, is currently focused on developing a vaccine against COVID-19. In the technology sector, the Indian start-up Azimov Robotics[7] has developed robots to serve COVID-19 patients (e.g. bringing them food and medicines, performing disinfection, and enabling video calls between the doctor and the patient).

Impact of the COVID-19 crisis on business research and innovation

Innovative companies were hit by lockdowns

Many businesses scaled back on innovation activities at the height of the lockdown. According to an April 2020 survey of innovative companies conducted by the German Federal Ministry for Economic Affairs and Energy, which received 1 800 responses (86% from SMEs), 54% of companies had suspended ongoing research and innovation projects, and 24% were planning to terminate one or more projects (BMWi, 2020[29]). An international survey and subsequent interviews of over 200 executives across industries conducted by McKinsey in April 2020 found that the focus on innovation as a core business priority had decreased across most industries – except the pharmaceutical and medical supply sectors – as companies sought to address immediate COVID-19-related challenges (McKinsey, 2020[30]).

Sharp decreases in demand during the first-wave lockdown period and reduced access to research infrastructures affected innovation. As is the case elsewhere, lockdown measures led to the closure of most innovation and testing facilities, labs and science parks. This had a direct impact on many firms' ability to progress with their planned research, product development and commercialisation activity, as set out in business plans and investor agreements. More broadly, early estimates for the OECD area suggested that in the absence of government intervention, 30% of firms would run out of liquidity after two months of confinement (OECD, 2020[31]). A survey of 414 technology firms conducted in Israel in May 2020 found that 54% of firms (and 65% of firms with under ten employees) would not be able to maintain operations for more than six months (Solomon, 2020[32]).

Innovation performance persisted and recovered

The evidence from patent data to date suggests moderate and short-lived impacts of the pandemic's first wave. Comparing trends in Patent Cooperation Treaty (PCT) patent applications between November 2019 and June 2020 with the same period year on year, OECD countries experienced on average a slowdown in patent filings following the COVID-19 outbreak. However, the pandemic itself has not resulted in a dramatic break in patenting trends. In the case of China, PCT patent filings in March 2020 even returned to the levels registered in March 2019, and in the OECD as a whole, the gap with the previous year seemed to be narrowing as of June 2020. Instead, reductions in innovation activities owing to COVID-19 may be reflected in patent applications in the coming months or years. Evidence from the 2008-09 financial crisis showed this pattern across many countries. The demand for digital innovations may, however, produce different trends for such inventions. For example, the finding that patenting in WFH in USPTO patent filings increased at the onset of the first COVID-19 wave (Bloom, Davis, and Zhestkova, 2020[26]) points to a different pattern. Interview evidence from 247 leading patenting firms also shows they have maintained their innovation activities, often by responding to new demands during the first wave of the COVID-19 pandemic (Kanesarajah and White, 2020[25]).

Asymmetric impacts of the COVID-19 crisis across sectors

The COVID-19 crisis has had unequal effects across economies. Some firms and sectors have been particularly hard hit, particularly those characterised by comparatively lower levels of innovation. Within the service sectors, the tourism, travel and leisure industries, as well as activities requiring contact between consumers and service providers (e.g. hairdressers and retailers), businesses were highly affected by restrictions on movement and social distancing. The same services are mostly being directly impacted by the re-confinement measures adopted to respond to the second wave of COVID-19 infections. The overall impact on business R&D is likely to be minor, since the average company's R&D investment in these sectors is low. However, more R&D-intensive activities were also impacted, including manufacturing sectors with long global supply chains (e.g. automotive and electronics), as demand for durables momentarily dropped. Demand gradually increased again as lockdown measures were lifted, except in those manufacturing industries that are directly linked to the tourism and transportation sectors.

Some businesses, particularly in the digital sector (e.g. cloud services, videoconferencing and digital collaboration tools, video streaming, online shopping, online learning and telemedicine), are thriving in this context and continue to innovate, with increased demand for their products. Figure 1.5 shows corresponding R&D investments in the digital sector as well as the pharmaceutical sectors, compared to a reduction in expenses among major companies in the automotive, aerospace and defence sectors.

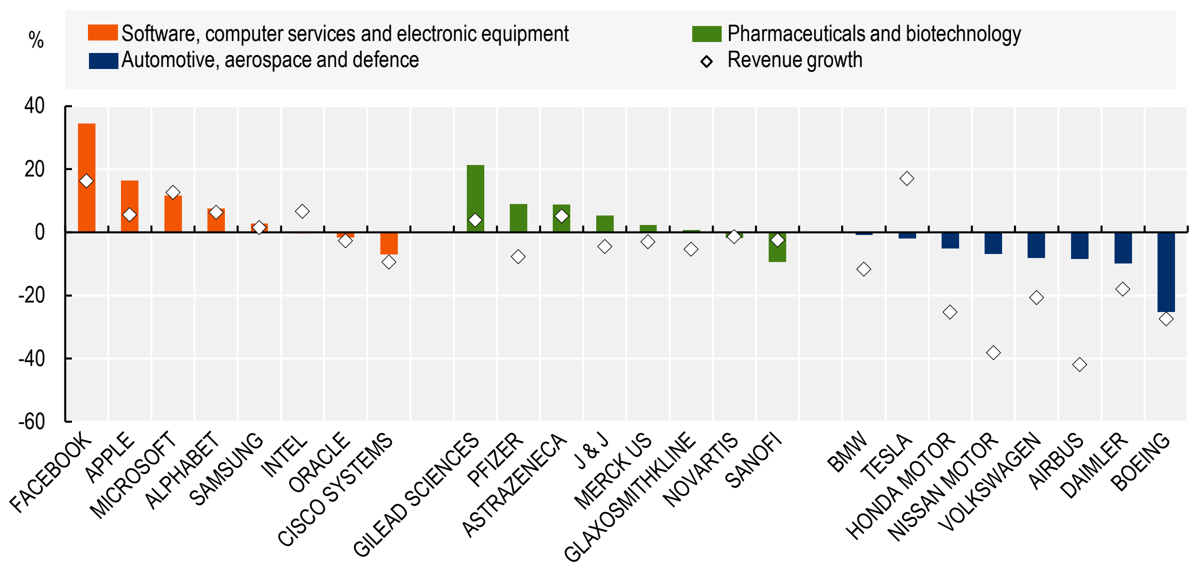
Business creation during the first wave of COVID-19

As is common in periods of crisis, lower new-business registrations and increased bankruptcies were observed in the first semester of 2020 compared to 2019 (Figure 1.6). Business registrations were down in Germany, France, Belgium and Iceland, but not in Norway, Japan, Sweden and the Netherlands, where enterprise creation was higher than during the first semester of 2019.

Early evidence for the United States shows that the initial shock of the first COVID-19 wave was short-lived, with a rapid rebound and surge in business applications (Dinlersoz et al., forthcoming[33]). The United Kingdom's Office of National Statistics also reported that the number of business creations in the United Kingdom in the third quarter of 2020 was slightly higher than during the same period in 2019, following a small fall in the second quarter of 2020 (Office for National Statistics, 2020[34]). While this is a positive phenomenon, it may only be temporary given future uncertainties. Moreover, some of the business creation may stem from individuals affected by unemployment temporarily opting for private business activities.

Figure 1.5. Reported R&D expense and revenue growth in selected R&D-intensive companies

Percentage change between April-September 2019 and April-September 2020

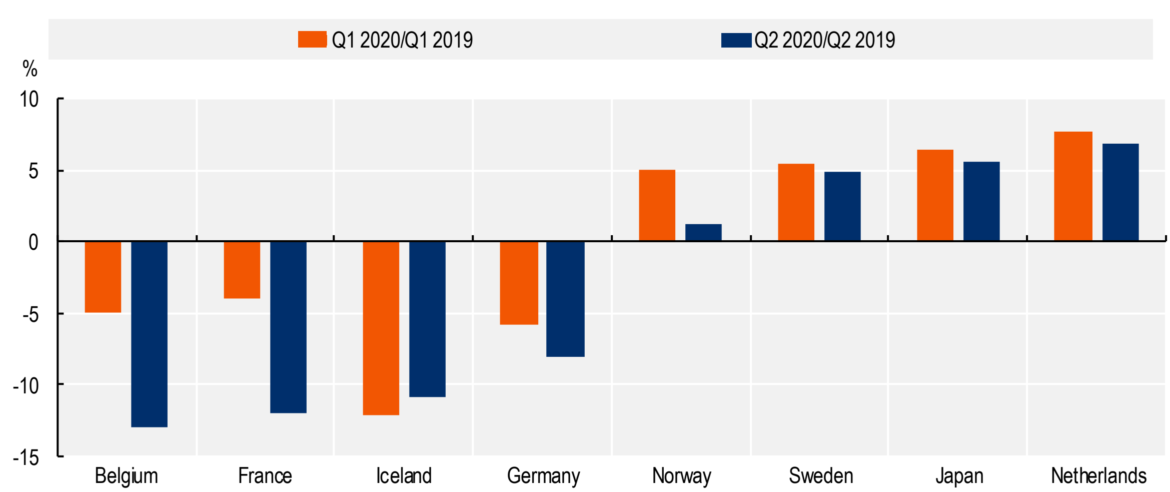


Note: R&D growth rates are in nominal terms and measured between April to September 2019 and April to September 2020. Data refer to the 6-month period from the beginning of April to the end of September, except for Cisco (May to October) and Oracle (March to August). Company reports of R&D expense need not coincide with R&D expenditures as covered in official R&D statistics compiled according to the Frascati Manual. Methodological information can be found in the StatLink below.
Source: OECD calculations, based on published quarterly business financial reports, December 2020.

StatLink https://doi.org/10.1787/888934223156

Figure 1.6. Growth rates in enterprise creation

Q1 2020/Q1 2019 and Q2 2020/Q2 2019 for a selection of countries



Note: The concept of enterprise "creation" reflected in the data series differs across countries. The OECD Timely Indicators of Entrepreneurship Database uses data based on national definitions only. An enterprise creation refers to the emergence of a new production unit. This can be either due to a real birth of the unit, or creations by mergers, break-ups, splitoffs or through the re-activation of dormant enterprises.
Source: OECD (2021[35]), "Timely indicators of entrepreneurship", Structural and Demographic Business Statistics (database), https://doi.org/10.1787/b1bfd8c5-en (accessed on 19 October 2020).

StatLink https://doi.org/10.1787/888934223175

Venture-capital funding for innovative entrepreneurship

Early evidence suggests that the COVID-19 shock affected VC and angel/seed investment, a key source of funding for innovative start-ups (OECD, 2020[1]). According to analyses by Ipsos MORI, the number of VC deals at the global scale declined between January and August 2020, reaching its lowest level since February 2013 (Ipsos MORI, 2020[36]). A survey of 1 000 mostly US-based institutional and corporate venture capitalists also found they slowed their investment pace (71% of normal) during the first half of 2020 (Gompers et al., 2020[37]). Evidence from many countries suggest that early-stage companies were hit harder by investment declines, including in China (Brown and Rocha, 2020[38]), Ireland (ICVA, 2020[39]), the United Kingdom (Ipsos MORI, 2020[36]) and the United States (Howell et al., 2020[40]).

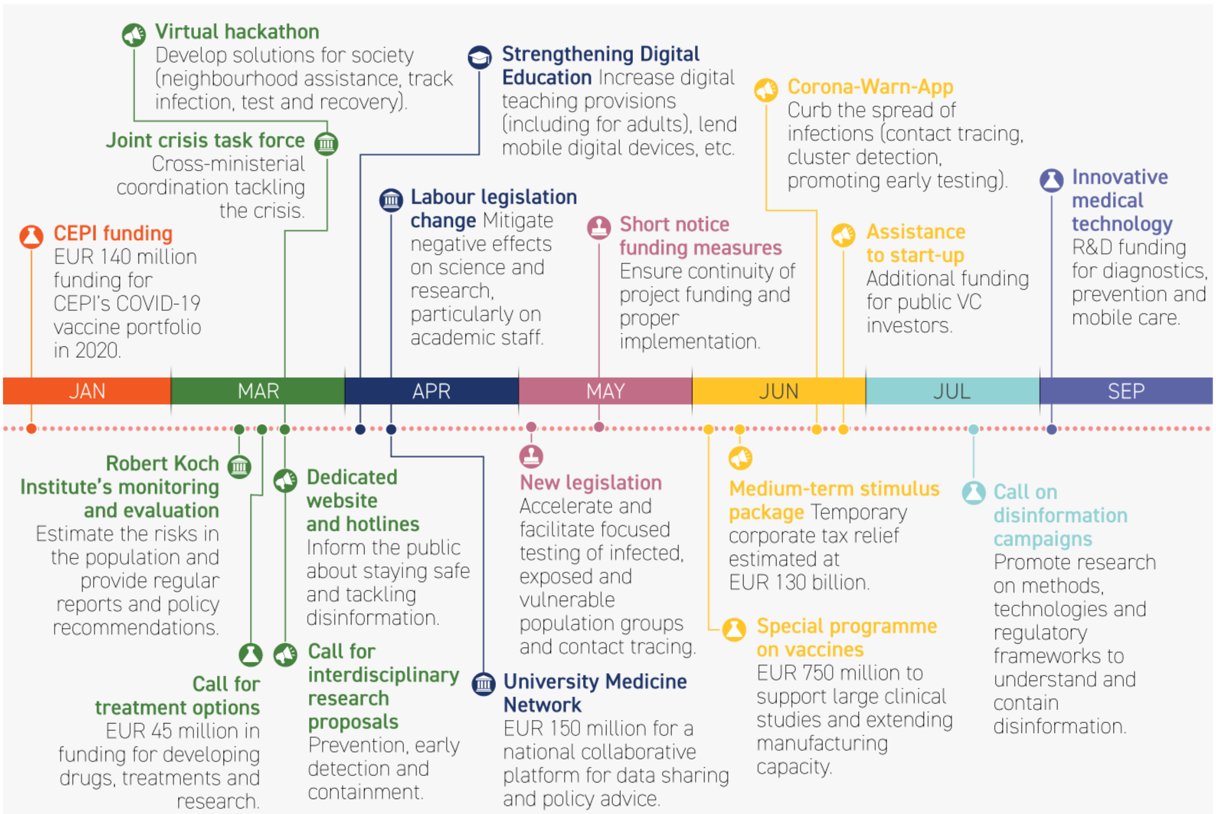
However, the aggregate shock to VC was much weaker than during the 2008-09 financial crisis, and VC activity had recovered relatively swiftly by July 2020. Indeed, the analysis by Ipsos MORI shows that the value of deals was already back to high levels by that date, although based on fewer large deals (Ipsos MORI, 2020[36]). The study by Gompers et al. (Gompers et al., 2020[37]) also notes that the slowdown in investments was more modest than during the 2001-02 dotcom bust (where investments declined more than 50%) and the 2008-09 global financial crisis (when investments declined by 30%). There exist, however, important asymmetries in funding, with more financing allotted to established larger firms and companies operating in sectors that benefited from the COVID-19 pandemic. This change in the distribution of VC funding may still challenge future innovation dynamics across different sectors and actors, notably early-stage companies.

Mobilising STI policies to combat the COVID-19 pandemic

STI policy responses to the COVID-19 pandemic

STI policy makers rapidly stepped up their responses to the COVID-19 pandemic, seeking to both mobilise and protect STI systems. Initial efforts directed resources at finding medical solutions (i.e. vaccines and treatments), and supporting innovation actors in research and industry hit by the pandemic shock. To address the socio-economic costs of the crisis, governments invested in STI, including through initiatives to boost digital services, enhance the capacity of public and private organisations to use these across education and industry, and tackle the spread of misinformation. Governments also established co-ordination mechanisms to ensure efficient STI responses and implementation of measures at different levels of government (see Chapter 8). For example, Ireland established a cross-governmental National Action Plan on COVID-19, and South Africa set up a National Command Council. Countries have implemented a wide range of measures. Figure 1.7 illustrates the measures implemented by Germany's federal government from January to September 2020.

Figure 1.7. Germany's federal level STI policy response to COVID-19, January-September 2020



Source: OECD (2020[4]), STIP COVID-19 Watch (https://stip.oecd.org/Covid.html).

Fast-tracking of research initiatives

Governments, firms and foundations have committed large amounts of funding for R&D activities aimed at developing vaccines, therapeutics and diagnostics for COVID-19. In the United States, the National Institutes of Health (NIH) alone had devoted USD 1.8 billion to research on COVID-19 as of April 2020 (Lauer, 2020[41]). The European Commission had mobilised EUR 1 billion (i.e. USD 1.2 billion) as of May 2020 under Horizon 2020, the EU framework programme for research and innovation (European Union, 2020[42]). 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,[8] a global health think tank, more than USD 9.1 billion had been committed by government, industry and philanthropic organisations as of 18 September 2020 to COVID-19 R&D projects. Nearly 60% of such funding has been allocated to R&D on vaccines, and around half of the funds have come from organisations located in the United States (Policy Cures Research, 2020[43]). The COVID-19 Research Project Tracker[9] jointly maintained by the UK Collaborative on Development Research and the Global Research Collaboration for Infectious Disease Preparedness shows a remarkable number of projects dedicated to studying societal responses to the COVID-19 crisis (see Chapter 2). As of September 2020, data from the OECD collection of COVID-19-related R&D funding show total public and philanthropic investments in R&D projects amounting to USD 6.6 billion (see Chapter 2) (OECD, 2020[4]).

As described in Chapter 2, many governments have fast-tracked competitive research-funding initiatives to support the development of COVID-19 vaccines, diagnostics and treatments. In March 2020, the French National Agency for Research launched a Flash COVID-19 call[10] for EUR 3 million (soon increased to EUR 14.5 million) allowing the evaluation, selection and funding of research proposals within a short period of time. In some cases, support is channelled through existing funding mechanisms to accelerate responses. In Canada, one of the measures of the Mobilize Industry[11] plan is to refocus existing industrial and innovation programmes (e.g. the Strategic Innovation Fund and Innovation Superclusters) on the fight against COVID-19. Some government calls also encourage existing grant holders to repurpose their research and innovation activities. The UK Research and Innovation (UKRI) grants programme for ideas related to COVID-19[12] invites researchers holding existing UKRI standard grants to switch the funding to COVID-19 priority areas (UKRI, 2020[44]).

Governments have also invested in improving the visibility of research-funding opportunities, often by creating online platforms that list all relevant information on STI activities related to COVID-19, such as the European Commission's European Research Area (ERA) corona platform[13] and Portugal's Science 4 COVID-19 portal[14] (OECD, 2020[45]).

Accelerating innovation to respond to COVID-19

Most countries have also implemented measures to stimulate quick innovative responses to the wide range of challenges posed by COVID-19 – from preventing virus transmission, to producing essential supplies, combatting misinformation and handling effects of the lockdown. Country approaches include:

- **Launching fast-track open competitions**. These seek to stimulate out-of-the box thinking by aiming for inputs from all parts of STI systems, including from firms, research teams and individual inventors. Ireland's COVID-19 Rapid Response Call and the United Kingdom fast-track competition for business-led innovation in response to global disruption are fairly open, and ask applicants to demonstrate the relevance of the COVID-19-related challenge they address with their innovations.
- **Organising or supporting virtual hackathons**. Hackathons are typically 24- to 48-hour events during which participants are provided with data they must use to create an innovative product. Winners are compensated with funding to develop and scale their ideas. In late April 2020, over 30 000 participants from across the European Union joined the EUvsVirus hackathon hosted by the European Commission and the European Innovation Council to address around 20 COVID-19-related challenges. More than 2 100 solutions were submitted across different challenge categories, with the highest contributions on health and life (898), business continuity (381), remote working and education (270), social and political cohesion (452), and digital finance (75). A total of 117 innovative solutions were identified, including a highly scalable patient monitoring system that minimises the need for physical contact between nurses and patients (European Commission, 2020[46]). The winners were invited to a "Matchathon" (and a Demo Day) in May 2020 to help winning teams match with corporations, investors and accelerators around the world to put their innovative solutions into production. This matching exercise generated more than 2 000 new partnerships (European Commission, 2020[47]).
- **Promoting research collaborations**. Governments are also launching initiatives to encourage research and innovation collaboration. In Canada, for example, the National Research Council Pandemic Response Challenge programme15 aims to mobilise Canadian and international researchers from universities, business and government to work together on specific COVID-19 challenges identified by Canadian health experts (Government of Canada, 2020[48]).
- **Supporting data and knowledge sharing**. Data-sharing initiatives have been launched to share epidemiological, clinical and genomics data, as well as related studies (see Chapter 5). Protocols and standards used to collect data are also being shared. The COVID-19 Open Research Dataset (CORD-19),16 created by the Allen Institute for artificial intelligence (AI) in collaboration with the US government and several firms, foundations and publishers, contains17 over 200 000 machine-readable scholarly articles on COVID-19 and related coronaviruses (including over 100 000 with full text), and serves as a basis for applying machine learning techniques to generate new insights for COVID-19 research. Other initiatives include repositories of genome data (e.g. Nextstrain18

and Gisaid),19 chemical-structure data (e.g. CAS COVID-19 data set on antiviral candidate compounds),20 clinical studies (e.g. ClinicalTrials.org) and data for modelling research (e.g. MIDAS).21

- **Introducing regulatory flexibilities where needed** to ensure rapid responses while maintaining safeguards. In the COVID-19 emergency context, regulatory flexibilities were introduced where feasible. In Australia, the Therapeutic Goods Administration, part of the Department of Health, has been prioritising regulatory assessment of applications for therapeutic goods related to COVID-19. In the United Kingdom, the Medicines and Healthcare Products Regulatory Agency published a package of regulatory flexibilities to support the healthcare response to COVID-19, including through expedited scientific advice and rapid reviews of clinical-trial applications, and expedited clinical investigations of medical devices.22
- **Initiatives to facilitate access to research infrastructures**, such as laboratories, databases and tools, have been launched to help researchers accelerate their activities (see Chapter 2). 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,23 while the European Research Infrastructure on Highly Pathogenic Agents offers access to in-vitro and in-vivo research capacities to researchers conducting studies on COVID-19.24
- **Setting incentive systems for intellectual property rights (IPR) to address the COVID-19 pandemic**. In May 2020, the USPTO launched a COVID-19 prioritised examination pilot programme to accelerate the examination of patent applications related to COVID-19 submitted by small and micro entities, without charging additional fees (USPTO, 2020[49]). An ongoing debate regarding the search for solutions to COVID-19 is how to harness IPR incentives in order to develop solutions without restricting access to those solutions.

Support for STI systems to withstand the pandemic shock

Aside from STI policy action to underpin research and innovation as it responds to COVID-19 challenges, the immediate STI policy response has focused on keeping innovative businesses afloat, and helping researchers and public research organisations adapt quickly to the new context. Such measures are often part of broader stimulus packages designed to boost the economy (e.g. the Coronavirus Aid, Relief, and Economic Security (CARES) Act in the United States),[25] which also directly or indirectly bolster STI actors. Compared to the 2008-09 financial crisis, the scale and speed of fiscal support provided by many countries during the COVID-19 crisis has been exceptional (IMF, 2020[50]). However, it is important to note that middle- and low-income countries have much more limited financial capacities to provide such support, and some countries are likely to need international assistance to weather the crises they are facing.

Immediate policy measures to address the negative impacts of COVID-19 on STI have included the following:[26]

- **Closely monitoring impacts of the crisis on different STI actors**. For example, Israel is conducting monthly surveys and has organised roundtables with essential stakeholders to obtain a comprehensive picture of the main challenges facing innovative businesses, and how these are evolving over time.
- **Introducing flexibilities for current beneficiaries of research and innovation programmes**. Most research-funding bodies have introduced flexibilities, as well as postponing application deadlines.
- **Supporting higher education institutes and researchers** – including early-career researchers – as they cope with short-term challenges. Measures have included helping higher education institutions provide academic staff with tools and training to effectively deliver their teaching activities online. Several measures aim to support PhD students: for example, UKRI is providing

grant extensions of up to six months to funded PhD students in their final year whose studies have been disrupted by the pandemic (see Chapter 3). In Germany, the Erasmus+ programme and German scholarship providers have flexibly revised their conditions for national and international students.

- **Supporting higher education and research institutes in protecting research jobs and research projects impacted by the pandemic**. Given the expected income loss from a decline in international students, the United Kingdom has launched a GBP 280 million (USD 361 million) scheme providing low-interest loans to universities to cover researchers' salaries and other costs, such as laboratory equipment and fieldwork, and to fund ongoing R&D projects.27
- **Facilitating access to funding for entrepreneurs and innovative firms**. Such support can take different forms, such as loans, grants and repayable advances. France launched a EUR 4 billion (USD 4.75 billion) Emergency Start-up Relief Plan, which provides 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 innovation grants under the Investments for the Future Programme.28
- **Helping businesses** – particularly SMEs and start-ups – adapt to the COVID-19 context. Enterprise Ireland provides Lean Business Continuity Vouchers up to EUR 2 500 (USD 3 200) to companies so that they can acquire training or advice on how to continue operating their businesses during the pandemic.
- **Using digital tools to design and implement research and innovation policy**. Such tools promote quicker and more effective decision-making, based on stronger evidence. 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.

Key uncertainties, critical pivot points, and their implications for STI systems and policy choices

The response to the pandemic raises several key issues where future developments are highly uncertain. Figure 1.8 sets out the key issues related to public research organisations and researchers, while Figure 1.9 does the same for key issues related to business research and innovation. In addition to these domain-specific issues, there exist broader "key uncertainties", e.g. related to societal and economic dynamics, technological change, and international relations, which will shape STI activities and policies over the coming months and years. "Going broad" is essential when thinking strategically about future developments, as changes emanating from outside one's own field of specialisation can often be the greatest source of surprise and disruption. The effects of a disruptive change like COVID-19 will be felt far and wide. Many impacts in other sectors will spill over and cascade through STI landscapes, with implications for STI policy. Some of these broader key uncertainties are particularly acute in the context of the pandemic and present "critical pivot points", where future developments could go in radically different directions. Mapping these pivot points, and outlining plausible yet sufficiently divergent visions of the future that capture a wide range of possible future developments, can make STI policy more agile and resilient.

Figure 1.8. Key issues emerging for public research organisations and researchers

Will public research funding shift towards new priority areas?
Public funding for research has an important influence on the type of research conducted and consequently the fields of scientific discoveries. The level of research funding for COVID-19 and other health research will depend on the course of the pandemic, but also on future policy orientations (e.g. an emphasis on essential goods and related research). In the absence of increased research budgets, additional spending on one issue will reduce funding elsewhere.

Will COVID-19 research dissemination practices accelerate the time needed to publish high-quality research?
The pandemic emergency has led to new ways of operating in science, notably by accelerating the speed at which research findings are published. This was achieved through a mix of methods, including new types of peer review and alternative publication formats. The obvious advantages from quicker publication have raised questions about possible downsides, particularly in terms of quality, but also the feasibility of faster publication processes if applied to all disciplines. Yet the pandemic experience may result in new debates on alternative publishing arrangements. Much will depend on whether it will be possible to guarantee the quality of the research published under such arrangements, in which case quicker dissemination may accelerate scientific exchange and ultimately progress.

Will the pandemic lead to a stronger push for open science?
To accelerate research, a vast amount of research data were made publicly available, along with investments to facilitate working with these data. A prominent example is the COVID-19 Open Research Dataset, discussed below. Other initiatives were also implemented and may generate new impetus for more open science. Nonetheless, several structural factors complicate expanding open science, which are neither obvious nor easy to resolve.

How diverse will the research workforce be?
The first wave of the COVID-19 pandemic has had an impact on research, especially challenging early-career researchers and women. With the second wave of the pandemic and continued social distancing measures, the question of possibly permanent effects on the diversity of the research workforce is pertinent. This directly relates to the discussion below on critical pivot points for inclusion and exclusion. The future workforce will also be affected by the impacts of the COVID-19 pandemic on the diversity of students choosing to engage in science, technology, engineering and mathematics disciplines, and more broadly in innovation activities.

Figure 1.9. Key issues emerging for the future of business research and innovation

How will business research and innovation respond to ongoing uncertainties?
Market uncertainties are known to limit business innovation. However, industry may identify fields of safe future demand – such as for environmentally sustainable technologies – if recovery packages feature large public funding commitments.

How inclusive will innovation be in the future?
This depends on whether sectoral innovation dynamics will create large imbalances in investment, whether certain regions will be further disconnected, and whether small-sized firms will keep up with their larger counterparts, favouring wider diffusion of STI. Changes in market concentration, driven by inequalities in the impacts of the pandemic, will also shape the future inclusiveness of innovation.

How will industrial research and innovation evolve in a context of countries seeking wider resilience to shocks?
The COVID-19 crisis led to shortages in "essential goods" stemming from a massive global demand shock, sometimes leading to production capacities being reassigned to meet requests for personal protective equipment, ventilators, etc. A potential shortening of global value chains, combined with changes in industrial patterns aimed at increasing resilience, might induce changes in business research and innovation performance in specific sectors. The extent of the changes will also depend on which items are included in the list of "essential goods".

How will entrepreneurship flourish in a context of ongoing uncertainties?
The future evolution of entrepreneurship will depend on how uncertainties will be interpreted, and to what extent opportunities arising from the pandemic (such as the demand for new digital ways of interacting, despite social distancing) will be seized by start-ups rather than established businesses (including large players in the field).

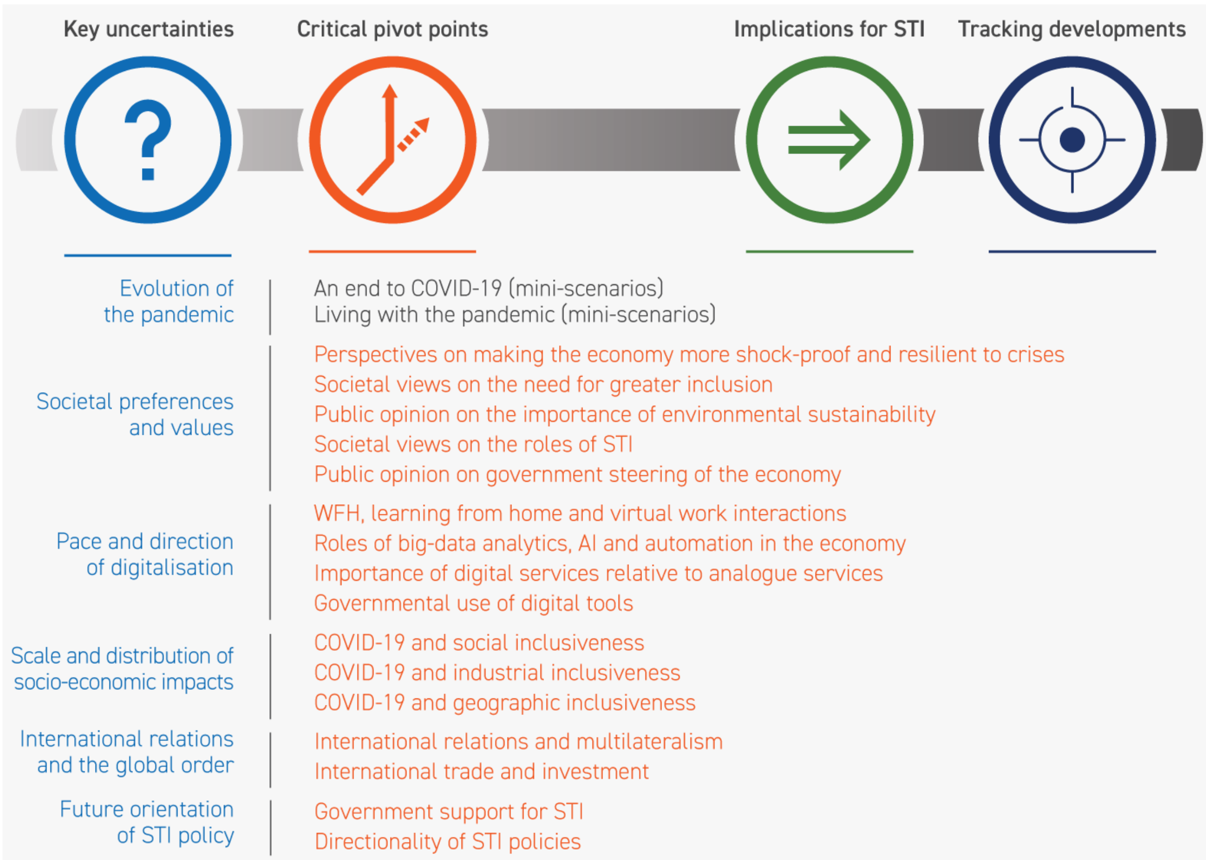
This section offers a stylised framework for systematically monitoring the evolution of the crisis and its impacts from an STI policy perspective (Figure 1.10). Given the fast pace of change during the crisis, providing such a framework, rather than just an ad hoc set of forecasts, can be useful. When combined with regular monitoring using indicators, it can operate as an early warning system that alerts policy makers (and others) to possible future developments. It also allows decision makers to keep sight of alternative pathways and outcomes they could pursue – or want to avoid. Indeed, the course of uncertainty is shaped by choices on the direction to be taken to avoid some obviously bad choices and pursue more promising ones.

The framework has four main elements:

1. **Key uncertainties**: the first step is to start with a limited set of high-level key uncertainties related to the pandemic crisis that are expected to have significant implications, including for STI and STI policy, as shown in Figure 1.10. How these key uncertainties unfold can be influenced by STI and STI policy, but is also somewhat influenced by exogenous factors. Other key uncertainties could be added later as users deploy the framework. In the version below, other crises and challenges, such as the climate emergency, are introduced as part of economic stability and recovery packages, but they could be included as standalone elements.
2. **Critical pivot points**: most of the key uncertainties covered here comprise critical pivot points, which refer to aspects of uncertainty where radically different development paths remain open. For the time being, each critical pivot point has just two opposing “mini-scenarios”, typically just a few sentences in length, to convey the main idea. Further mini-scenarios could be developed for each critical pivot point in a more comprehensive exercise.
3. **Implications for STI**: this element presents very briefly some of the implications of the critical pivot points’ opposing mini-scenarios for STI and STI policy. These are pitched at a high level and are somewhat speculative, as is typical of such exercises. Developing these implications further would be an important part of a more comprehensive and deliberative process.
4. **Tracking developments**: if the framework is to be used to track emerging developments, it should identify “leading indicators” at the level of the key uncertainty itself, but also covering the more specific effects on STI. As far as possible, these indicators should also be quantitative, but they could also be qualitative (e.g. news stories about the impacts of the crisis on firms or their activities and new policy announcements), signalling directions of future development. Given the lag times both in the appearance of effects and their measurement, nowcasts and short-term forecasts would be useful, although they are not especially well-developed in the STI policy field. On the other hand, STI-related activities tend to react slowly, particularly on the public research and innovation side, where long-term commitments, sunk costs and lock-ins are common. The section below briefly discusses some of the indicator options. It includes quantitative leading indicator charts for a few key uncertainties, both to draw attention to particular phenomena and demonstrate the framework in action.

The following sections explore six key uncertainties, as shown in Figure 1.10. The first key uncertainty is the evolution of the pandemic. Two main scenarios are outlined; they are presented here more as a backdrop to the other key uncertainties, and their implications for STI policy are not explored. The next four key uncertainties – on societal preferences, the pace and direction of digitalisation, inclusiveness and global relations – and their critical pivot points are set out in tables that also briefly outline the implications for STI and suggest possible leading indicators to track future developments. The tables are accompanied by an introduction of the issues at stake and their implications for STI, followed by a short summary of developments to date. The final key uncertainty – on the future orientation of STI policy – is treated differently than the others, in a more discursive style, as it is more endogenous to the STI field and a central concern of many STI policy makers. Even here, considerable uncertainty remains on the extent of future government support for STI given the worsening economic conditions, and the degree to which government support will be directed at challenges, such as the “green transition” that is encapsulated in several national recovery packages (OECD, 2020[51]).

Figure 1.10. Framework for considering the key uncertainties around COVID-19 and critical pivot points, with implications for STI



This framework is likely to evolve as it is used and as the crisis unfolds. This first version is therefore highly provisional, subject to further development through adoption and use. Policy makers and STI system stakeholders could use the framework to engage in an exercise that provides an international perspective on key uncertainties and critical pivot points, mapping their evolution to complement national efforts. These elements could also be building blocks for developing exploratory scenarios of future STI systems, which would help governments systematically appraise a wide range of policy options to shape the future state and dynamics of STI landscapes.[29]

The uncertain evolution of the COVID-19 pandemic

The course of the COVID-19 pandemic remains unknown, even with the regulatory approval of the first vaccines. Governments are tackling the “second wave” of the pandemic through containment measures that weigh on socio-economic activities, including the forced closure of restaurants and bars, the issuance of travel warnings and constraints, and lockdown measures of various severity. Uncertainty on the spread of the virus, the potential duration and form of restrictions, and the possibility of future new restrictions have prevented a full return to pre-crisis activities, particularly those involving social interactions and travel.

This uncertainty has had a negative impact on societal and economic optimism, despite the relatively good performance of STI across several dimensions in the early months of the pandemic, and the steady recovery of trade and economic activity as demand resumed. Massive stimulus packages implemented across the developed world have reduced even more substantive shocks, at least in the initial period.

Whether effective vaccines or treatments will remove the threat of COVID-19 (signifying “an end to COVID-19”), or whether the virus will remain a threat for years to come (“living with the pandemic”), various changes to future social and economic life are possible. Multiple scenarios on the course of the pandemic can also be envisaged (Scudellari, 2020[52]). Two are briefly outlined below:

- A quick solution bringing an end to COVID-19, either through effective vaccines and/or treatments, could mean a return to more-or-less business-as-usual. Practices that grew out of necessity during the pandemic, such as WFH, limited or no business travel, and use of online health and education services, would largely be reversed. However, successful experiences with some of these practices may lead to their continuation, even after the pandemic crisis has passed. Moreover, a shorter-lasting pandemic would offer a quicker economic recovery. Industry and governments would have the means to make the necessary investments to improve the technologies allowing such practices to flourish. They could also take measures to prepare against future shocks and disruptions, including those that will likely arise from the climate emergency.
- Living with the pandemic could lead to forced long-term changes. It may also result in a return to previous practices, despite ongoing pandemic risks, on account of the huge economic costs and reduced public acceptance of containment measures. In the context of the second wave of the pandemic, many governments are attempting to implement efficient social distancing to reduce COVID-19 cases while reducing economic damage as much as possible. If “living with the pandemic” results in a prolonged period of economic downturn, this would affect investments in socio-technical sustainability transitions.

Working out what scenarios like these might mean for STI activities is far from easy. The following section discusses various key uncertainties related to the pandemic and the critical pivot points they pose for the global economy, as well as their implications and significance for STI.

Key uncertainties and critical pivot points presented by COVID-19

Societal preferences and values

The issues at stake and their implications for STI

The COVID-19 pandemic and the resulting lockdown measures – leading in April 2020 to the confinement in their homes of more than 3.9 billion people – have affected the lives of most of the world’s population. In such a context, social preferences and their translation into future policy priorities may change. For instance, the experience of collective action during the crisis could spur new forms of solidarity, while collective narratives about the COVID-19 crisis could bring the link between environmental sustainability and societal resilience to the fore, leading societies to seek more balance in environmental, economic and social priorities (OECD, 2020[53]). At the same time, public opinion and societal views are far from being monolithic in democratic societies. There are varieties of opinions, values and interests at play, often competing with but also complementing one another. Recent years have seen greater polarisation of societies in many OECD countries, sometimes manifest as “culture wars” or inter-generational conflicts, which have been driven in part by growing inequalities, and the rise of identity politics and “populist” political parties.

Public opinion and societal preferences are shaped by numerous factors that are largely impossible to disentangle, though this does not make them any less important as influences on public policy. The management of the COVID-19 pandemic (e.g. the restrictions implemented and their effectiveness in controlling the spread of the virus, and the communication of scientific advice to the public), as well as the socio-economic impacts of the crisis (e.g. the level of reliance of the economy on sectors largely unaffected by the crisis, and the impacts on inclusiveness) are likely to have implications on how societies view government intervention in general, the roles of science in society, and the need for greater attention to sustainability, inclusivity and resiliency. Table 1.1 outlines several critical pivot points related to the impacts of COVID-19 on societal preferences and possible implications for STI.

Table 1.1. Critical pivot points in societal preferences and values

Impacts of the COVID-19 crisis: Critical pivot points
Perspectives on making the economy more shock-proof and resilient to crises *Factors favouring resilience as a key policy goal*: the COVID-19 crisis raises social awareness of the vulnerabilities of the real economy to shocks, favouring policy action to create more resilient economies. *Factors against resilience as a key policy goal*: the crisis is seen as an exceptional occurrence, which will not be repeated, and the changes needed to make economies more resilient are viewed as too costly. Consequently, there is little demand from society for more shock-proofing of the economy
Societal views on the need for greater inclusion *Factors favouring inclusion as a key policy goal*: problems of social and economic exclusion were exposed and exacerbated during the crisis. Inclusiveness as a goal gains ground in policy agendas as social movements like #MeToo and Black Lives Matter permeate political and social spheres. In the economic sphere, the dominance of big companies is seen as detrimental to socio-economic well-being and leads to a wider call to support SMEs. *Factors against inclusion as a policy goal*: the need to recover after the extensive economic shock relegates inclusiveness to a lesser priority. Movements such as nationalist groups advocating exclusion gain greater traction. Big companies provide products consumers demand and use their resources/capacities to respond to COVID-19 challenges, leading to implicit public endorsement of their dominance.
Public opinion on the relative importance of environmental sustainability *Factors favouring sustainability as a key policy goal*: the COVID-19 shock raises public awareness of the need to tackle climate change and environmental degradation as a key policy priority, as they pose risks of future shocks at an unprecedented scale. *Factors favouring less public support*: public opinion downplays the climate challenge as health matters and economic recovery (including preserving jobs at any cost) gain in importance.
Societal views on the roles of STI *Factors favouring STI*: public support for STI increases as it is seen to provide the only long-lasting solutions to the COVID-19 crisis, e.g. through the rapid development of an effective vaccine. *Factors against STI*: public opinion turns negative towards STI, e.g. because scientific advice is seen as a “culprit” for unpopular confinement measures and other restrictions.
Public opinion on government steering of the economy *Factors promoting more government “steering”*: the experience of the shock results in the perception that government needs to help “steer” markets to protect vulnerable crisis-prone economies. Trust in government interventions increases thanks to the perceived usefulness and effectiveness of actions taken to offset the negative impacts of COVID-19. *Factors against public opinion favouring government steering*: unpopular lockdowns and high death tolls mean public perceptions of government responses to the COVID-19 shock are unfavourable, which reduces public support for government to play key roles in steering the economy.
Examples of implications for STI
Transformative STI policies: societal perspectives on the importance of transforming socio-technical systems to be more resilient, inclusive and sustainable in the recovery would influence the objectives of STI policies and the policy instruments they use. For example, STI policies would be more directed towards social goals if society places greater value on issues of sustainability and inclusivity. **Scale of STI policy support**: societal opinion on the intensity of government intervention and the roles of STI would shape support for STI in stability and recovery packages. For example, if society views both STI and government intervention positively, STI would play prominent roles in ambitious recovery packages. **Reach of STI systems**: beyond influencing politics, changes in societal perceptions of STI will affect the influence of STI on society (e.g. people’s trust in scientific advice and their resulting actions), as well as the ability of STI to draw on new talent (e.g. more students engaging in scientific careers).
Tracking developments – indicator examples
Key uncertainties: public opinion surveys on priorities; public opinion surveys on trust in government and trust in science advice; analysis of media, social media and online searches; mapping of government policies and legislation; and analysis of civil society activities (social movements, demonstrations, responses to surveys). **Implications for STI:** mapping R&D expenditures by socio-economic objectives, the SDGs, etc.; mapping the prominence of STI in government stability and recovery packages, and associated strategic orientations, as well as industry/labour association statements on directing innovations at sustainability, resilience and inclusiveness goals.

Tracking developments on public perceptions of the roles of STI and governments

Perceptions of the roles of STI in the first phases of the crisis appear to be positive. For example, findings based on a survey of 2 651 people across England, Wales and Scotland, carried out between 30 March and 26 April 2020 show that 72% of respondents trusted health scientists and researchers completely or to a great extent to deal with the crisis (Craig et al., 2020[54]). Responses to questions in the OECD Science Flash Survey 2020 on scientific advice and trust suggest that researchers expect an increase in the use of scientific evidence, enhanced reputation of science, and a wider use of scientific advice after the crisis (see Chapter 8). They also expect scientific careers to become more attractive.

However, these positive perceptions may not necessarily last. New social distancing measures to counter the second wave of COVID-19 infections, drawing on scientific advice, have resulted in public demonstrations in a number of countries. More debate has raged about the proportionality of confinement measures given the state of infections, and more active resistance has taken place among those most affected by confinement decisions.

As for public opinion on governments' handling of the pandemic, the EU annual Regional and Local Barometer, a survey conducted in September 2020 showed a 44% average share of EU citizens (based on 26 381 responses from all EU countries) trusting their national governments to take the right decisions to overcome the socio-economic impacts of the COVID-19 crisis. This compared to 48% who said they do not trust their national governments in this regard. Levels of trust vary substantially across countries, however, being typically higher in the Nordic region and lower in Central and Eastern Europe. Trust levels are likely to evolve over time as the crisis unfolds.

Pace and direction of digitalisation

The issues at stake and their implications for STI

The role played by digital technologies, big-data analytics and AI in the economy and society during the crisis also represent a critical pivot point. Changes in the organisation of work (with increased remote working and virtual interactions); the rapid expansion of digital services (e.g. digital health and education tools); and the increased use of big data analytics, AI and digital tools by industry and government are putting those technologies to the test.

These developments also have important impacts on STI, both because they mark new processes that may change the productivity of STI systems, and because they are changing demands for STI (e.g. in terms of better WFH technologies and progress in virtual reality), potentially spurring new waves of technological innovation in these fields.

Whether digital technologies, big-data analytics and AI will take on more important roles in society and the economy will depend on several factors, including their contributions to addressing the COVID-19 crisis. The success of WFH, virtual conferencing, robotics (see Chapter 6), and virtual services in health, education and entertainment will also play a role. Experience in managing the crisis using digital tools will also influence governments' future use of such tools. Table 1.2outlines several critical pivot points related to the impacts of COVID-19 on the socio-economic role of digital technologies, and their possible implications for STI.

Table 1.2. Critical pivot points in the socio-economic role of digital technologies, big-data analytics and AI

Impacts of the COVID-19 crisis: Critical pivot points
WFH and virtual work interactions *Factors for an increase in WFH and virtual work*: the confinement experience stemming from the pandemic leads to widespread experimentation with WFH and virtual exchanges. Many professional workers prefer at least part-time WFH. Firms see their cost structures shift as office space is reduced and becomes more flexible to accommodate fewer staff on-site at any one time. *Factors against more digital work and consumption patterns*: negative experiences with WFH, particularly shortcomings of virtual conferencing in promoting effective exchanges, reduce interest in WFH and lead to limited development and uptake. Infrastructure constraints and security fears also raise concerns, slowing the wide uptake of these technologies.
Roles of big-data analytics, AI and automation in the economy *Factors for increased uptake of digital technologies in the economy*: the shock to the labour supply – caused by the confinement measures enforced to reduce the spread of the first wave of the COVID-19 pandemic – leads to more automation of factories. The possible reshoring of economic activities may also result in more automation, to reduce labour costs from reshoring to locations where labour is expensive. At the same time, positive business experiences with big-data analytics and AI lead to more widespread interest and adoption. *Factors for less uptake of digital technologies*: a perceived lack of impact of AI and digital technologies in addressing the COVID-19 crisis may weaken their wide adoption. Emphasis on other priorities – for example, investments in health innovation – diverts attention away from AI and automation. Abuses of privacy; the dominance of big players; digital threats; the misuse of high-quality language models for misinformation, spam and, phishing; and abuse of legal and governmental processes may reduce their application, as could biases in AI-based applications.
The importance of digital relative to analogue services *Factors for a surge in digital services*: the widespread experience of digital services in education, health, and retail is positive and leads to their wider application. *Factors against an increased rollout of digital services*: experiences of digital services were generally unsatisfactory during the pandemic and lead to a return to previous services. This may be reinforced by concerns over privacy (especially with regard to health data) and the increased market concentration in the delivery of these services.
Governmental use of digital tools *Factors for increased use of digital tools in government*: the COVID-19 crisis showed the benefits of real-time data to feed agile policymaking. This leads to increased use of new real-time and digital applications across governments, drawing on a mix of data sources. *Factors hampering the uptake of digital tools in government*: negative experiences with digital tools, e.g. owing to technical problems, data quality, privacy concerns, lack of digital skills among officials, and concerns over private-sector involvement, lead to weak uptake across government until such challenges are resolved.
Examples of implications for STI
Increased demand for digital innovations: if digital technology use intensifies, there will be demand pressure for improved digital tools, which would generate new waves of technological innovation. **Changes to operations and performance of STI systems**: any changes to WFH and virtual interactions would affect the operations of STI systems. For example, they could lead to greater automation in science. Progress in STI critically depends on connections: while digital technologies could open these up further, they could reduce in-person exchanges, which could be detrimental. **Changes in the innovation intensity of services:** digitalisation may increase the innovation intensity of this traditionally less innovation-intensive set of industries, as well as the types of businesses operating in services. **Changes in STI policies' focus**: STI policy itself would gain in agility and responsiveness by applying new digital tools, and improvements in its effectiveness could in turn affect the performance of STI systems' performance.
Tracking developments – indicator examples
Key uncertainties: survey evidence on the uptake of WFH, big data, cloud services and AI application; diffusion of digital technologies in businesses of various sizes, in households/by individuals and in government/by industry. **Implications for STI**: indicators of digital and AI-driven innovation, as well as WFH and online education tools technologies (e.g. software applications and patents), geographic distribution of research collaborations (e.g. international and national, etc.).

Tracking developments on the uptake of digital technologies

COVID-19 has been called the "great accelerator", particularly when it comes to digital technologies[30] enabling e-commerce, teleworking, telepresence and automation. Early evidence points to actors in the STI system having adopted more digital tools during the crisis. For example, a survey by the Centre for Economic Performance-Confederation of British Industry survey of 375 UK businesses in July 2020 found that from late March 2020 to July 2020, over 60% of firms adopted new digital technologies and management practices, and around one-third invested in new digital capabilities (Riom and Valero, 2020[55]). Digitalisation has also had an impact on research. Over half of the respondents to a survey of professionals and decision makers at 247 patenting companies cited digitisation as the most significant change (Kanesarajah and White, 2020[25]). AI tools have also been used to help accelerate drug and vaccine development, identify virus-transmission chains, rapidly diagnose COVID-19 cases, monitor broader economic impacts and tackle misinformation (OECD, 2020[56]). For example, based on a data set comprising 1.8 million papers from three pre-print repositories (arXiv, bioRxiv and medRxiv) gathered at the end of May 2020, Mateos-Garcia, Klinger and Stathoulopoulos (Mateos-Garcia, Klinger and Stathoulopoulos, 2020[57]) found that more than one-third of AI publications related to COVID-19 involved predictive analyses of patient data, particularly medical scans. These papers, however, received fewer citations than comparable papers on the same topic.

Digital services in education, health, entertainment, retail and restaurants were much used concurrently with confinement measures, and have led to an unprecedented demand that continued even as the strict confinement measures were lifted. Whether all of these services remain in the event the COVID-19 challenge is resolved currently seems unlikely: some reduction in demand would be expected where virtual services are judged an imperfect substitute for their in-person alternatives.

Governments themselves have shown unprecedented agility in their use of digital tools, most exemplified by the contact-tracing applications introduced as a way to control the spread of the disease. The COVID-19 crisis has also shown how policy making has also changed compared to the 2008-09 financial crisis, as illustrated by the use of real-time data (such as Google's mobility statistics) and other tools to better monitor and respond to the crisis. A series of pulse surveys have also been informing STI policies. The open release of COVID-19 papers by initiatives such as CORD-19 has not only supported scientific activities, but also helped identify the nature of scientific collaboration on COVID-19. Early analysis of such data has pointed to a drop in female research activities and high reliance on existing networks for research collaborations, for example. These types of tools could be more systematically used in the future to support the responsiveness and agility of STI policies. For example, the Portuguese Foundation for Science and Technology launched AI 4 COVID19, a competition endowed with a budget of EUR 3 million (USD 3.6 million) for R&D projects on data science and AI that help improve public administration bodies' response to the impact of COVID-19 and future pandemics.

Scale and distribution of socio-economic impacts

The issues at stake and their implications for STI

The extent to which policy measures help avoid strong negative distributional effects will be an important critical pivot point shaping STI systems and policy. This will depend on several factors, including the intensity of the COVID-19 shock and the related confinement measures, and the availability and uptake of digital technologies and practices by different actors. Socio-economic exclusion influences the operation of STI systems and the diffusion of new technologies. A combination of more limited means to invest in leading technologies and a more limited ability to retain qualified staff to operate those technologies in difficult times explain why exclusion negatively affects diffusion. Table 1.3 outlines several critical pivot points related to the impacts of COVID-19 on inclusion and exclusion, and their possible implications for STI.

Tracking developments on the scale and distribution of socio-economic impacts related to COVID-19

As discussed earlier in the chapter, the asymmetric impacts of the COVID-19 shock on innovative businesses, universities and public research institutes, the research workforce and entrepreneurs highlight the different distributional challenges of the COVID-19 shock. One risk is that existing gaps in the uptake and use of digital technologies are exacerbated, in particular between large firms and SMEs, but also between sectors. If not addressed, such uneven diffusion may have important implications for firms' productivity performance as the pandemic continues to accelerate digitalisation. It could potentially widen the productivity gap between digital adopters and digital laggards, enhance the vulnerability of laggards, and reduce economic resilience. Greater policy efforts will therefore be needed to boost adoption and diffusion of digital tools, in particular for SMEs.

An additional dimension concerns the geographic impacts of the COVID-19 shock. Differences in effects across sectors have influenced the intensity of the shock at regional levels (Bailey et al., 2020[58]). For example, regions highly specialised in the tourism sector are among the hardest hit by the crisis (Gössling, Scott and Hall, 2021[59]; OECD, 2020[60]). These sectors were also most affected by "social distancing" measures aiming to reduce international and national travel, as well as social gatherings. As the crisis unfolds and other sectors are hit hard in the resulting recession, further regions are likely to suffer more than others.

Table 1.3. Critical pivot points regarding the distribution of socio-economic impacts

Impacts of the COVID-19 crisis: Critical pivot points
COVID-19 and social inclusiveness *Factors pointing to more exclusion*: the pandemic provides fewer opportunities for new connections for recent graduates, job seekers and people with precarious contracts (often including younger workers and people in contract-based professions) and has a negative effect on the female workforce, taken up by dependent (children or elderly) care. The demand for a constant online presence may also exacerbate the hurdles for those providing more dependent care. *Factors pointing to more inclusion*: the shock leads to even more awareness of inclusiveness challenges, which were somewhat hidden prior to the COVID-19 pandemic. Accordingly, stability packages and related policy action highlight greater inclusion as an explicit goal. Changes in practices owing to COVID-19, such as WFH and digital services, offer opportunities for more inclusion. The goal of achieving greater resilience also aligns with promoting inclusive economic processes across firms, regions and individuals.
COVID-19 and industrial inclusiveness *Factors pointing to less inclusiveness*: government recovery packages primarily focus on the big employers (airlines, large manufacturers, etc.). Big tech companies, but also other large firms, benefited from large demand for their products during lockdowns, possibly reducing opportunities for smaller firms in the digital and other sectors to compete. *Factors pointing to more inclusiveness*: policy responses aimed at shielding the economy from the crisis have successfully targeted the financial fragilities of SMEs, particularly young innovative firms, which emerge as catalysts for radical innovation. The pandemic provides new opportunities for entrepreneurship, where start-ups help address the constraints created by difficult health and economic conditions, and respond to changing preferences and needs.
COVID-19 and geographic inclusiveness *Factors pointing to less inclusiveness*: the COVID-19 crisis was geographically unequal as outbreaks differed across and within countries, the effects across sectors (e.g. tourism vs. digital tech) and regions varied, confinement measures were more or less severe, and countries' capacities to respond differed (e.g. depending on the level of government debt/ability to borrow). *Factors pointing to more inclusiveness*: policy efforts to support the regions and sectors most affected, and regional measures to control outbreaks and mitigate the negative effects of the pandemic were implemented. New ways of providing goods and services (such as online entertainment offers) helped reduce unequal sectoral effects. The urban-rural divide may also be lessened as rural areas become more popular by virtue of the higher exposure to the pandemic in cities and the reduced cost of participating in professional activities remotely through digital tools, rather than engaging in time-consuming commuting
Examples of implications for STI
Impacts on STI system performance: the crisis presents different innovation opportunities for different players across firms, regions, countries and social groupings. More diversity is conducive to more innovation, while concentration has mixed effects on innovation outcomes. Greater inclusivity can increase market competition, which may raise the rate of innovation (albeit in non-linear ways). **Impacts on STI policy**: if inclusiveness is taken seriously, STI policies will pay greater attention than in the past to those that are more excluded, including women and minorities, and innovation in low- and medium-tech sectors and in 'laggard' regions. This would mean a greater focus on technology diffusion policies and STI policies to support inclusiveness more generally.
Tracking developments – indicator examples
Key uncertainties: Gini indices and distributional measures at regional, firm and individual levels in response to COVID-19. **Implications for STI**: various STI performance indicators (e.g. scale and scope of publications, graduates, IP, etc.) by region (incl. rural-urban divide), firms (by size, sector, age), and individuals (profiles of entrepreneurs and researchers).

The issues at stake and their implications for STI

There exist considerable uncertainties about the future of the current multilateral system, and what this could mean for international STI co-operation and mobility. On the one hand, there are signals that "peak" globalisation has passed, and that a new fragmented global order – marked by a rise in ethno-nationalism, more managed trade and investment, and greater strategic competition between "great powers" – is emerging. Furthermore, the current crisis may contribute to undermining trust in global governance solutions, fuelling the already growing pre-crisis discontent and ultimately driving a shift towards national approaches as countries – especially larger economies – seek to become more self-reliant. These tendencies could be augmented by multinational enterprises seeking to rely less on global value chains to reduce uncertainty and enhance their resilience, leading to further "reshoring" of production.

On the other hand, multilateral frameworks could be reinforced as a result of a greater appreciation of risks and challenges that transcend national boundaries and require co-ordinated responses, especially if transnational actors in the public and private sectors are successful in leading the fight against the pandemic. Table 1.4 outlines critical pivot points related to the impacts of COVID-19 on the international political economy.

Table 1.4. Critical pivot points on international relations and the global order

Impacts of the COVID-19 crisis: Critical pivot points[31]
International relations and multilateralism *Factors pointing to strong multilateralism*: the cascading systematic effects of the pandemic as well as its indiscriminate nature serve as a strong argument for renewed endorsement of multilateral co-operation. It illustrates that global responses are needed to global crises, spurring countries to engage in greater international collaboration. The global health emergency and economic aftermath trigger a major new commitment to development co-operation that moves beyond a traditional North-South approach to focus on multi-directional mutual learning and solidarity. The SDGs' holistic vision of development is reinforced as there is a new appreciation of interconnectedness and interdependence of human development outcomes and human security. *Factors pointing to faltering multilateralism*: The multilateral system begins to break down due to lost credibility and resources, and unilateral or bilateral actions and decisions prevail, making way for new but competing institutions, power players and alliances. Emerging and developing economies see a rise in regional multilateralism, while the 'old powers' are preoccupied with internal issues and divisions and abdicate leadership internationally
International trade and investment *Factors pointing to sustained international trade and investment*: the COVID-19 crisis catalyses new global trade and investment links to address localised supply shocks. Accelerated digitalisation enables a new wave of globalisation that is more transparent and efficient. The efficiency gains from international collaboration and the international division of labour in production introduce a large cost to autarchic behaviour, particularly in a period where rebuilding economic growth is essential. *Factors pointing to preferences for national or supranational regional approaches*: the COVID-19 crisis has already elicited international competition to secure scarce global resources. Wider geopolitical tensions increase national or supranational efforts to safeguard against future shocks, including in the provision of essential goods. The shock created by the pandemic and the shortage of key products during the crisis may amplify demands for access to key technology fields, such as 5G communications and AI, in light of concerns over national security, the risk of future dependencies on foreign technology suppliers, and concerns over global monopolies and their potentially detrimental impact on technological progress.
Examples of implications for STI
Impacts on STI systems: disruptions in international scientific collaboration and the international division of labour in production would affect the performance of STI systems, as well as shift the orientations of national STI (as a substitute or complement to global efforts). **Impacts on STI policies***:* STI policies may focus on existing national specialisations and support international scientific collaborations to optimise the global STI system. Alternatively, STI policies may be technology- or product-specific in order to ensure national access to core technologies or products. Strategic STI alliances with chosen countries may also be sought to exploit shared values and the reciprocal benefits and costs of such collaborations
Tracking developments – indicator examples
Key uncertainties: measures of the evolution of barriers to international collaboration and economic exchanges, e.g. trade and investment data, data on global value chains, government funding of multilateral organisations, etc. **Implications for STI**: measures of the nature and extent of international STI collaboration, e.g. patent and publication data, research funding data.

Tracking developments on international relations and the global order

In co-operation with national governments, a diverse range of foundations and international organisations are actively engaged in STI actions to respond to COVID-19. The WHO, the Coalition for Epidemic Preparedness and Innovation, and the Global Research Collaboration for Infectious Disease Preparedness (to name just a few) are playing prominent roles co-ordinating the development of vaccines and therapeutics (see Chapter 5). The foundations involved in this endeavour include the Bill and Melinda Gates Foundation, the Wellcome Trust and the Novo Nordisk Foundation. Among other objectives, these globally operating foundations seek to harness science and innovation to address infectious diseases. In the context of COVID-19, they have not only provided research funding, but also promoted STI responses to COVID-19 at the global level, with special emphasis on the challenges faced by developing countries.

Several bilateral and supranational regional approaches have also supported research collaborations. For example, the National Research Foundation of Korea and the Swedish Research Council launched a grant programme for joint research collaborations between Swedish and South Korean researchers on the control and prevention of COVID-19, while the Nordic Health Data Research Projects on COVID-19 is a collaborative call for proposals for funding to promote research co-operation and sharing of health data across Sweden, Finland, Denmark, Norway, Iceland, Estonia and Latvia.[32]

A large number of research outputs have also been international. Analysis of research papers published on COVID-19 from January 2020 to September 2020 shows that around half of UK-based authors, one-quarter of US-based authors and one-quarter of China-based authors co-published their papers with an international co-author. Chinese collaborators represent by far the largest share of co-authors in the United States, and vice versa (see Chapter 5).

At the same time, the COVID-19 crisis has also shown that an important component of the scientific response has occurred at the national level. National institutes working on infectious diseases, such as the Institut Pasteur in France and the Robert Koch Institute in Germany, have played central roles in advising domestic policy makers on the means to address the national COVID-19 situation.

The future orientation of STI policies

STI policy is shaped by the key uncertainties above, but it also influences them. Compared to the situation during the 2008-09 global financial crisis, STI lies at the heart of solutions to the COVID-19 crisis and has a highly visible part in shaping policies to contain the virus's spread. The role played by STI in this context is therefore likely to influence the positioning of STI policy in the future. However, there are also uncertainties on the future goals and practices of STI policies and the resources they will have at their disposal. This section considers future levels of government support for STI, in light of the highly visible contributions STI is making to solve the pandemic, but also the public sectors' growing indebtedness. It also considers whether STI policy will become more directional to enact sustainability and digital transitions over the medium and longer term.

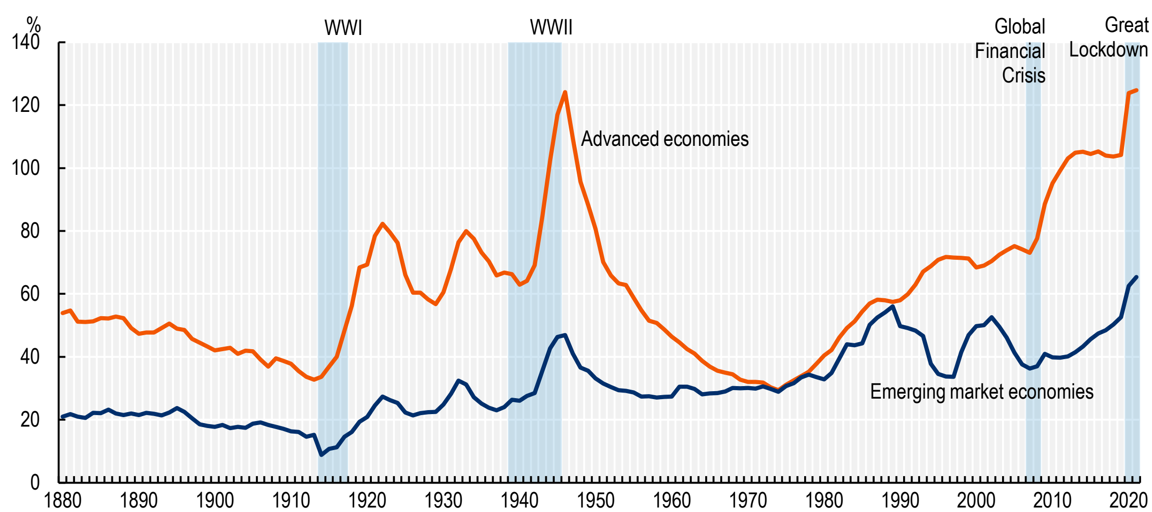
Government support for STI

Future levels of government support will be determined by societal preferences and the recognition of STI as an essential actor of socio-technical transitions to meet sustainability, inclusiveness and resilience goals. Strong endorsement and recognition of STI could lead to significant increases in public R&D – the equivalent, perhaps, of the West's reaction to Sputnik, which ushered in the US-Soviet space race (Subbaraman, 2020[61]). This could become a reality as the United States, China, other Asian industrialised countries and Europe chase leadership positions in AI, quantum computing, supercomputing, robotics (see Chapter 6) and other technologies, particularly health-related (see Chapter 7 on engineering biology). Most OECD governments are launching recovery packages to help overcome the longer-term fallout of the pandemic crisis. Many have lofty ambitions to modernise national economies, particularly through digitalisation, and drive a green transition towards more sustainable production and consumption. Some also proclaim greater "technology sovereignty" as a goal.

However, the extent to which ambitions like these translate into actions that drive structural change remains uncertain. Government intervention also needs to be affordable, which will be a major concern for many countries as the pandemic raises the costs to the economy. Following the first wave of COVID-19 infections, government debt for all countries was already at an unprecedented high, far above the levels reached during the global financial crisis (Figure 1.11). The current level of support for research and innovation emulates behaviour in 2008-09, when funding was impressive in the immediate aftermath but dropped-off in a number of countries because of unsustainable levels of public debt. While some countries will have few difficulties obtaining credit, others will not be so fortunate. The impacts of COVID-19 are already substantive, and not all countries have been in a position to support those most adversely affected by COVID-19. This applies notably to developing countries, which have left a number of their industries unsupported. This has implications for STI, as the scale and focus of recovery packages will affect the goals and types of measures supporting research and innovation that governments choose to implement, as well as the level of funding.

Figure 1.11. Historical patterns of general government debt

Percentage 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: International Monetary Fund (IMF). 2020. Fiscal Monitor: Policies for the Recovery. Washington, October.

StatLink https://doi.org/10.1787/888934223213

At the same time, the amount of public funding is not necessarily synonymous with support for STI systems, as industry and civil society also play a role. As a possible remedy to funding constraints, industry and civil society actors – notably foundations – working jointly with public research and innovation-funding agencies can amplify the impacts of public support.

Directionality of STI policies

Public preferences on the need to build more resilient, sustainable and inclusive societies, as well as perspectives on the limits of government intervention, will shape the goals and toolboxes of STI policy.

The move towards a more proactive "systems transformation" model, compared to a model mainly focused on eliminating market failures, could accelerate. This could be reflected in ambitious mission-oriented projects aiming to engage a wide range of stakeholders from across the STI system (see Chapter 8). Such projects may feature prominently in government recovery and stimulus packages, particularly those that emphasise green and digital transformations. STI policy has well-established roles to play in supporting the development of sustainable technologies (e.g. by investing in environmentally sustainable technologies) and responding to the need for greater inclusiveness (e.g. by enabling the participation of excluded groups in STI) (OECD, 2011[62]; Planes-Satorra and Paunov, 2017[63]; Borowiecki et al., 2019[64]). OECD countries have been increasing their support programmes along these lines over the last decade or more, and could now expand them. While STI policy may need to adjust to the new emphasis on building greater socio-economic resilience, STI already makes important contributions in this regard, as outlined in Box 1.1.

Box 1.1. The contributions of STI to building resilience

STI systems can contribute to building resilience in the following ways:

- An agile STI system that operates effectively can help find responses and solutions to unexpected challenges. In the context of the COVID-19 crisis, the STI system has the capacity to develop vaccines and treatments quickly (e.g. through novel technology platforms) and ways of dealing with the virus (e.g. through tracking apps and finding alternative ways to reduce infection rates while keeping the economy operating). It has also developed a range of digital technologies that have helped much of the economy and society continue its operations through remote working and electronic business. However, STI systems need to remain agile, as future crises – including health crises and other shocks – will likely require very different responses than those that apply to COVID-19.
- STI plays an important role in ramping up the production of goods and services that can help address a crisis. During the initial onslaught of the COVID-19 pandemic, several countries were able to bolster critical production quickly, thanks to their strong technological and industrial base, and using new tools and technologies such as 3D printing and open-source designs and software. More widely, technological strengths in core fields – such as biotechnology, the digital sector and AI – provide the means to respond to shocks to global production.
- While the exact timing and type of future shock cannot be predicted, a number of crises are foreseeable. Preparedness measures can benefit from STI efforts aiming to avert crises before they emerge and build resilience to their consequences. Future shocks may emerge from climate change, including its impacts on health, biodiversity and food production. Dealing with such contingencies means that STI must contribute to sustainability.
- Scientific advice is also essential to helping develop effective responses to future crises. Scientific advice can contribute to the preparedness of research systems, anticipating likely knowledge and infrastructure requirements needed to support socio-economic systems in times of crisis. Multi-disciplinary advice structures that simulate future crises can contribute to national contingency planning efforts in case of emergencies.

Conclusions

Science is the only exit strategy from COVID-19, and the chapter shows that the pandemic has triggered an unprecedented mobilisation of the scientific community. Science and innovation have played essential roles in providing a better understanding of the virus and its transmission, and in developing hundreds of candidate therapeutics and vaccines over a very short period. The pandemic has underscored more than in other recent crises the importance of science and innovation to being both prepared and reactive to upcoming crises. It has also stretched research and innovation systems to their limits, revealing gaps that need filling to improve overall system resilience and preparedness for future crises. It is a wake-up call for all and highlights the need to recalibrate STI policies to better equip governments with the instruments and capabilities to point innovation efforts towards the goals of sustainability, inclusivity and resiliency.

A range of relevant STI policy goals and actions will help implement this orientation for the recovery and meet the challenges of the current crisis, as shown in Table 1.5.

Table 1.5. Broad STI policy goals and actions for crisis and recovery

STI policy goals	Examples of STI policy actions
Direct STI to identify solutions to the COVID-19 pandemic	• provide research and innovation funding for diagnostics, as well as vaccine and treatment development • support areas of research and innovation, including social sciences, that contribute solutions to COVID-19 and mitigate the negative effects of measures taken to contain the spread of the pandemic • support international collaboration on STI solutions to the shared global challenge of COVID-19.
Mitigate the negative impacts on STI systems, including the uneven distributional effects of COVID-19	• offer support to public research institutes in light of potentially reduced funding resulting from the pandemic (e.g. because of lower student intake) • support early-career researchers and women researchers who are more affected by the disruptions caused by the crisis • support innovative SMEs and entrepreneurs affected by the COVID-19 crisis • invest in the diffusion of digital technologies to help companies deal with confinement measures • support the agility of the STI system by providing grant extensions to innovators affected by COVID-19, including innovative SMEs.
Provide scientific advice to policy makers and the public on appropriate responses to COVID-19	• manage the trusted communication of scientific evidence on COVID-19, including its limitations as more is learnt (including dealing with misinformation) • offer transparent perspectives on the trade-offs of decisions and the role of science in informing (but not deciding on) policy decisions • communicate the contributions of STI to dealing with the impacts of COVID-19 (paying close attention to social media and possible echo chambers) • tackle disinformation on scientific evidence regarding COVID-19.
Raise the agility and responsiveness of STI systems	• set policy directions that meet societal goals, including inclusiveness, sustainability and resilience • use such directionality, e.g. in recovery packages, to reduce uncertainties for businesses and other non-governmental actors, by signalling intended investments and future demand commitments in support of transition goals • revisit the policy mix, e.g. in support of business innovation, if more direct measures are necessary to meet ambitious transition goals • use the crisis an as opportunity to reform those parts of research systems that operate sub-optimally, e.g. the research-career pipeline • use new policy tools for optimal and agile support of STI to address COVID-19 problems, leveraging new digital technologies for policy making (e.g. real-time data, digital apps and interconnected databases) • use deliberative and anticipatory approaches to policy that systematically consider broader dynamics and the longer-term.

The need remains for medical research and innovation to contribute solutions to the pandemic, and support for these should continue – including international collaboration, given the global scale of the challenge. Collaborative partnerships provide STI systems with greater agility to respond to future challenges. Policy support for other areas of science and innovation that mitigate the effects of the crisis should also continue, paying close attention to the uneven distributional effects of COVID-19. With the onset of the second wave of the pandemic, scientific advice to policy makers and citizens is increasingly contested. This calls for renewed emphasis on transparency and a multidisciplinary approach, and a clear presentation of scientific advice as just one – albeit important – input to the policy-making process. Finally, if the post-crisis recovery is to promote the structural reforms required to meet an agenda focused on a transition to sustainability, then STI policies will need to reform research and innovation systems. Governments will also need to prepare more effectively against future shocks, assessing developments around key uncertainties and their implications for STI. Policy makers and STI system stakeholders could use this chapter's key uncertainties framework to appraise a wide range of policy options to shape the future state and dynamics of STI landscapes.

Outline of the book

The remainder of the book dives more deeply into several topics covered in this chapter. Chapter 2 takes a closer look at the intense pressure of COVID-19 on research systems, revealing their inherent response capacity and flexibility. Scientific production, in terms of academic publications, has been impressive. Research databases and scientific publishers have removed traditional barriers, so that the scientific community can quickly share COVID-19-related data and publications. Digital tools and open-data infrastructures have allowed many scientists to continue to function effectively outside their usual laboratory or field environments. COVID-19 has also shed light on areas needing strengthening to increase research systems' overall preparedness for (and resilience to) future crises, bringing to the fore pre-existing concerns about risk-taking in research and research quality. In the rush to understand and find solutions to COVID-19, the tendency has understandably been to support "safe" mainstream research, but there also exists a need to take calculated risks and explore new ideas that might lead to breakthroughs. The intense pressure to release data and results rapidly has cut short or circumvented normal peer-review publication processes, though the sharp rise in pre-prints appears to have caused relatively few problems, and experiments are under way to "speed review" such papers before they are released.

Even in the absence of COVID-19, many early-career researchers were in precarious positions, employed on short-term contracts with no clear perspective of a permanent academic position (Chapter 3). For women in particular, the hyper-competitive environment and lack of security have been an active disincentive to continuing in research. Most early-career researchers now expect to have even fewer academic career opportunities, a situation compounded by the radically disrupted international mobility of researchers. New and more attractive career paths that provide greater security and alternative options for mobility in and out of academia and other research sectors are required.

Regarding business research and innovation, the COVID-19 crisis is not just a key threat to the ability of innovation systems to fulfil their normal functions, but also a call for mobilising these systems to provide new solutions to the immediate health, societal and economic challenges posed by the pandemic (Chapter 4). On an aggregate basis, business investments in research and innovation are pro-cyclical, and thus prone to contracting in times of crisis. It is difficult to imagine the current crisis being any different, given its deep – although uneven – economic impacts so far. Nevertheless, governments cannot act alone to drive ambitious policy programmes (such as sustainability transitions): they require strong partnerships with business and civil society to succeed. Recovery packages will need to include a mix of measures incentivising the private sector to invest in appropriate research and innovation. An important policy goal will be to reduce uncertainties by signalling intended public-sector investments and future demand commitments supporting transition goals. The current crisis also serves as a reminder that innovation-support policies need to be able to guide innovation efforts where they are most needed. Governments need to build innovation-support portfolios that equip them with the mechanisms, instruments and capabilities allowing them to orient innovation efforts, particularly to areas where government is a primary user or customer of innovations. In this regard, tax incentives are an insufficient means of guiding innovation to broader societal needs, and are suboptimal for encouraging investment in knowledge at the interface between basic research and actual product or process development. Direct grants can support longer-term, high-risk research, as well as target specific areas that either generate public goods (e.g. health and defence) or have a particularly high potential for spillovers. Governments should revisit their policy mix in support of business research and innovation to ensure an appropriate balance between direct and indirect measures.

Just as the pandemic is a global problem, it requires global solutions involving international co-operation and collaboration (Chapter 5). No single country can beat COVID-19 on its own. Research collaboration, both between public research and businesses, and internationally, is perhaps unparalleled as the global scientific enterprise has pulled together to find solutions to the pandemic. The speed with which research groups and biopharmaceutical firms are developing COVID-19 vaccines builds on years of basic research investment, as well as the recent institutionalisation of international co-ordination efforts to develop agile technology platforms that can be activated as new pathogens emerge. These relatively new arrangements are performing well, but are underfunded and dependent on a handful of countries and philanthropic institutions for financing. Governments should consider scaling them up and extending them to other global challenges where R&D preparedness is important, capitalising on the momentum from the response to COVID-19. R&D preparedness measures include technology platforms, infrastructures, and collaborative networks that will improve countries' abilities to respond effectively to a diverse range of risks. Governments also need to work together on new financing and governance mechanisms, wherein business and private-finance actors work with multilateral and national development banks to co-finance STI solutions for global challenges. The rapid and unprecedented mobilisation of public and private R&D funding for COVID-19 vaccines and their global distribution has demonstrated that new innovative funding models can be deployed to address global challenges through international STI co-operation.

Digital and biomedical technologies are playing essential and highly visible roles in combatting the pandemic's impacts and in finding medical solutions, particularly with regards to rapid vaccine development. Two emerging technologies, engineering biology and robotics, have shown promise in helping enhance the health resiliency of societies. Engineering biology (Chapter 7) is an attempt to turn biotechnology into a discipline more reminiscent of engineering than biology, and is focused on industrial production. A recent technological breakthrough, the biofoundry, can greatly reduce the time from idea to product, and improve the reliability and reproducibility of bio-manufacturing. Biofoundries are highly automated facilities that follow detailed, complex workflows through the co-ordinated use of laboratory robots. The messenger RNA vaccines for COVID-19 (e.g. the Pfizer and Moderna vaccines that have been the first to clear clinical trials) are especially amenable to this approach. Beyond their use in biofoundries, robotics can play other roles that enhance the health resiliency of societies (Chapter 6), from aiding laboratory research, surgery and physical rehabilitation, to delivering medicines, transporting waste, combating loneliness, and improving medical diagnostics and treatments. Governments possess several tools to accelerate the development and deployment of technologies like these: basic and applied research in public research organisations and firms; public private partnerships and collaborative platforms; interdisciplinary and transdisciplinary research for converging technologies; and test-beds, demonstrators, and regulatory sandboxes to help companies de-risk investments. Skills development is another important requirement, as is support for standards and technology diffusion.

Countries' governance arrangements shape their research and innovation responses to the current COVID-19 crisis and will influence the contribution of STI to the recovery (Chapter 8). These arrangements are broad in scope and include the ways governments set directions and choose priorities, their relationships with other actors in the innovation system, and the technologies they use to govern. One of the more visible – and most debated – aspects of governments' response to the pandemic is the use of scientific advice in designing policies. Previous OECD work has formulated guidelines on providing and using scientific advice in international crises like COVID-19. The chapter reviews these guidelines and considers how governments have followed them in their policy making. The effectiveness of STI policies also depends on the policy intelligence tools used, including data-management systems and information services that detect, monitor and communicate developments in STI systems. These can map system dependencies, alert decision-makers to shocks and communicate the real-time impacts of possible future shocks at a granular level. The COVID-19 crisis has led to unprecedented uses of new digital tools and data to inform policy, which could accelerate the digitalisation of science and innovation policy itself.

Governments' ongoing experiments with mission-oriented innovation policies, which have tended to target grand societal challenges, could feature more prominently in the STI policy mix, for instance, as part of recovery packages targeting green transitions. Governments will need to renew their policy frameworks and capabilities to carry out a more ambitious science and innovation policy agenda. Chapter 8 argues that governments should link support for emerging technologies to broader missions that encapsulate responsible innovation principles. This will help ensure an alignment of emerging technology development with the objectives of mission-oriented innovation policies. Building government capabilities to deliver on a more ambitious policy agenda, including capacities to use advanced analytics more effectively and across the whole of government, will be paramount. An increased policy emphasis on building resiliency, which calls for policy agility, highlights the need for governments to possess dynamic capabilities to adapt and learn in the face of rapidly changing environments.

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Notes

[1] Both policy papers are a result of work conducted on COVID-19 under the auspices of the OECD Working Party on Innovation and Technology Policy.

[2] https://www.nytimes.com/interactive/2020/science/coronavirus-vaccine-tracker.html.

[3] The impacts on research infrastructures have been multifaceted, with sometimes extensive and enduring effects. As an illustration, the ability to observe the ocean was impacted in unprecedented ways. In the second quarter of 2020, governments and oceanographic institutions recalled nearly all oceanographic research vessels to home ports, and ocean buoys and other systems could not be maintained, leading to premature failure. The observations from these systems are vital to marine, climate, and weather forecasts and warnings, and some time and extra costs will be required to bring back these capabilities (Heslop et al., 2020[65]).

[4] This OECD Science Flash Survey 2020 is implemented through an online open-link questionnaire, inviting scientists or any other individuals with an interest in science or science policy to answer questions on the impact of the COVID-19 crisis from a science perspective. The survey was initially promoted through the network of the OECD Committee for Scientific and Technological Policy and former participants of the 2018 OECD International Survey of Scientific Authors. It is being carried out in collaboration with the Inter-American Development Bank. As of 12 October 2020, over 2 600 responses from nearly 100 countries had been collected; 45% of responses came from individuals who identify themselves as scientists; the remainder correspond to science policy advisors (20%), professionals involved in science (15%), science communicators (10%) and individuals carrying out science-related administrative work (10%). The survey does not request any information that can identify the respondents. As a result, results cannot be considered representative of a well-defined population and should be considered with extreme caution, as a complementary view to other evidence.

[5] http://www.zentech.be.

[6] https://www.adaptvac.com.

[7] https://www.thehindu.com/news/national/kerala/kerala-government-hospital-deploys-robot-to-serve-covid-19-patients/article31432663.ece.

[8] https://www.policycuresresearch.org/covid-19-r-d-tracker.

[9] https://www.ukcdr.org.uk/covid-circle/covid-19-research-project-tracker.

[10] https://anr.fr/en/call-for-proposals-details/call/flash-call-covid-19.

[11] https://pm.gc.ca/en/news/news-releases/2020/03/20/prime-minister-announces-canadas-plan-mobilize-industry-fight-covid.

[12] https://www.ukri.org/funding/funding-opportunities/ukri-open-call-for-research-and-innovation-ideas-to-address-covid-19.

[13] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/covid-19.

[14] https://www.science4covid19.pt.

[15] https://nrc.canada.ca/en/research-development/research-collaboration/programs/pandemic-response-challenge-program.

[16] https://www.semanticscholar.org/cord19.

[17] As of the end of September 2020.

[18] www.nextrain.org.

[19] www.gisaid.org.

[20] https://www.cas.org/covid-19-antiviral-compounds-dataset.

[21] https://midasnetwork.us/covid-19/.

[22] https://www.gov.uk/guidance/mhra-regulatory-flexibilities-resulting-from-coronavirus-covid-19.

[23] https://www.whitehouse.gov/briefings-statements/white-house-announces-new-partnership-unleash-u-s-supercomputing-resources-fight-covid-19/.

[24] https://www.erinha.eu/covid19-research/.

[25] https://home.treasury.gov/policy-issues/cares.

[26] A more comprehensive review is provided in (Paunov and Planes-Satorra, forthcoming[2]).

[27] https://www.gov.uk/government/news/government-to-protect-uk-research-jobs-with-major-support-package.

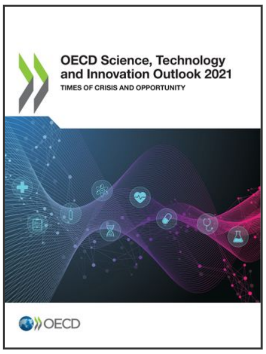
[28] https://lafrenchtech.com/en/covid19-french-tech-fights-back-n1/.

[29] Such an exercise would not start from scratch and would scan existing forward-looking analyses, including national foresight exercises and future scenario studies, to identify and explore key trends, forecasts and future scenarios that could usefully inform strategic long-term thinking in STI policy in a post-COVID-19 world. Using dedicated workshops conducted over the course of 2021 and 2022, the exercise would deliver a unique global perspective and provide useful resources for STI policy making and other strategic foresight studies. It would also provide a useful basis for the 2022 edition of the *OECD Science, Technology and Innovation Outlook*, which could provide compelling shared visions on the future of STI policy.

[30] Some of the issues raised in this section are explored more extensively in the latest edition of the OECD's Digital Economy Outlook (OECD, 2020[66]).

[31] These critical pivot points draw upon (Paunov and Planes-Satorra, forthcoming[3]).

[32] https://funding.nordforsk.org/portal/#call/1904.



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