How will COVID-19 reshape science, technology and innovation?

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This policy brief discusses the effects that the COVID-19 crisis could have on the future of science, technology and innovation (STI) and its policies. Factors shaping the future of STI include the unequal effects of the crisis on research and development (R&D) across sectors, the accelerated adoption of digital tools and techniques, and changes in the openness, inclusiveness and agility of research and innovation ecosystems. STI policy could see fundamental changes as resilience, environmental sustainability and inclusiveness become more prominent objectives on policy agendas. The crisis could also spur experimentation with new tools, policy approaches and governance models.

Key recommendations

- **Ensure sustained funding for research and innovation conducted by universities, public research institutions and firms in the aftermath of the COVID-19 crisis**. Science, technology and innovation (STI) plays a critical role in building a more resilient, sustainable and inclusive future. Yet the experience of the 2008-09 global financial crisis showed that maintaining R&D funding levels was a challenge for many countries, damaging their innovation capacities including through brain drain of researchers.
- **Take action to ensure that STI systems become more inclusive, and support diverse research career paths**. Women, early-career researchers and students from disadvantaged backgrounds have been disproportionally affected by the pandemic. More flexible work arrangements for those with childcare responsibilities, programmes to attract and support students from all backgrounds to pursue scientific and technical career paths, and more visibility for early-career researchers can be valuable. Innovation does not only take place in public research labs and promoting diverse research career paths improves the ability of societies to react to future challenges that require science-based responses.
- **Strengthen support to innovative businesses most affected by the crisis, particularly smaller innovative firms, to safeguard competitive markets**. Supporting access to funding to mitigate liquidity constraints will be critical to addressing widening gaps in innovation performance between firms that saw demand for their products increase – including digital and health services – and those that faced reduced sales, such as tourism and transportation. Cash constraints especially challenge small innovative firms; given their role in vibrant innovation systems, the levels of debt they incurred during the crisis demands attention.
- **Adopt systemic and collaborative approaches to STI policies to transition towards more inclusive, sustainable and resilient futures**. Effective transformations require exploring policy mixes and ensuring that they are well aligned within the STI field and across policy domains. They also require effective collaboration across government, industry, research and civil society. Breaking down siloes and enabling more trans-disciplinary innovation can help enable system transformation. Moreover, the pandemic has shown that countries cannot tackle global challenges on their own; effective responses demand international co-operation.
- **Account for the complementarities and trade-offs between the key objectives of STI policy and develop metrics to track performance**. Pursuing multiple policy objectives of competitiveness, sustainability, resilience and inclusiveness requires a better understanding of how to achieve those objectives, and any complementarities and trade-offs that may arise. Operationalising a new set of policy goals also requires developing new metrics and key indicators, particularly on resilience but also on inclusiveness and sustainability.
- **Leverage better real-time, granular data and new opportunities to gather such data for policy**. An unprecedented amount of real-time and granular data (e.g. mobility data, pulse surveys) has been collected during the crisis. Big data analytics, semantic analysis and visualisation tools have been applied to use such data for policy. Expanding and improving their use could allow for more agile, tailored and ultimately more effective policy responses, but this requires important investments in infrastructure for data management, guaranteeing data privacy and digital security, as well as providing training on how to use those data and tools.
- **Continue to monitor and explore the critical uncertainties generated by the pandemic and its aftermath, including plausible future disruptive changes at the systemic level and potential implications for STI and STI policy**. This will enable ongoing design of more innovative and effective STI policies and a more agile and productive STI system.

The COVID-19 pandemic and its effects on socio-economic activities may result in lasting changes for science, technology and innovation (STI). It may also affect the purpose, design and execution of STI policies. This brief, which is based on Paunov and Planes-Satorra (2021[1]), illustrates the array of possible future trends for STI and their effects on different actors, including firms, research organisations, universities, and the current and future STI labour force. These developments will in turn critically affect the speed and direction of future innovation, as well as its impacts on well-being and market dynamics.

The *OECD Science, Technology and Innovation Outlook 2021*, released in January 2021, highlighted how the COVID-19 pandemic threatens to cause long-term damage to innovation systems at a time when science and innovation are most needed to deal with the climate emergency, meet the Sustainable Development Goals, and accelerate the digital transformation. It emphasised the need for countries to implement measures to protect their innovation systems as part of their stimulus and recovery packages. It also recommended a shift in STI policy towards supporting a more ambitious agenda of system transformation that promotes a managed transition to a more sustainable, equitable and resilient future (OECD, 2021[2]).

The COVID-19 pandemic has had substantial impacts on STI systems and will have unpredictable cascading implications for STI systems for years to come. In this context, STI policy making should be based on a more comprehensive understanding of the complexity of ongoing developments and intertwined effects across different parts of the system. Such an understanding of critical uncertainties and possible future developments will help to design innovative and adaptive STI policies and build an STI system that is itself more agile, resilient and productive under a wide diversity of future conditions.

Possible long-term impacts of the COVID-19 crisis on science, technology and innovation

The COVID-19 pandemic has generated significant uncertainty across all aspects of the global economy and society. Likewise, the pandemic's long term impacts on science, technology and innovation are impossible to predict. In this context, it is instructive to explore some of the different (and sometimes contradictory) possible trends for how the pandemic could affect STI in terms of overall spending, digital infrastructure, openness, inclusiveness, and global collaboration.

Challenges ahead for STI spending

Insights from past crises point to two main challenges for future STI spending that could have lasting effects on countries' innovation performance. The distinctive characteristics of the COVID-19 crisis, however, suggest that dynamics are likely to differ from those following the 2008-09 global financial crisis and vary significantly across countries.

- **Unequal business expenditure on R&D may affect the dynamics of innovation across sectors**. Business expenditure on R&D (BERD) and innovation move in parallel with GDP, slowing markedly in times of economic downturn such as the 2001-02 recession and 2008-09 global financial crisis. This pro-cyclical trend is due to the fact that decreased demand and growing market uncertainties during periods of crisis reduce available funds and incentives to make risky investments in STI. Since the onset of the pandemic, however, demand for a number of health and digital tools and services has increased, while other sectors (e.g. automotive, aerospace) were hit hard, pointing to **highly unequal dynamics across sectors** (Paunov and Planes-Satorra, 2021[3]; OECD, 2021[4]; OECD, 2020[5]; OECD, 2020[6]). In countries where sectors with sustained revenues and demand for innovation account for an important share of total value added, increases in BERD in these sectors may compensate, at the aggregate level, for the effects of declines in other sectors.
- **Public funding for STI could be under pressure in the years to come** because of increased levels of public debt across the world, which could reduce funding for public universities and research

institutions. The extent of such funding reductions will also depend on the evolution of student intake, philanthropic donations and research contracts in institutions for which those revenues were an important source of income. In countries most severely affected by budget cuts for STI, the risk of brain drain of highly skilled workers (including scientific authors) could rise, as experienced in the aftermath of the 2008-09 global financial crisis in countries such as Greece, Italy, Portugal and Spain. On the other hand, the **central role of STI in addressing the COVID-19 pandemic and the economic crisis resulting from it could provide fresh impetus for enhanced policy support for STI**. This could lead to significant increases in public investments in STI, including for universities and public research institutions. Health-related STI, in particular, may benefit from such investments, especially those aimed at preparing for future pandemics. Other sectors or technology domains (e.g. Industry 4.0, artificial intelligence [AI]) could also receive higher funding if they are identified as strategic to enhancing preparedness to future shocks and challenges, including climate change.

Accelerated adoption of digital technologies and tools for STI

Virtual communication and conferencing tools enabled new forms of research collaboration, knowledge exchange and the provision of training during the pandemic (Paunov and Planes-Satorra, 2021[3]). These could remain after the crisis and affect future dynamics of STI in the following ways:

- **Working from home** could allow for more flexible work engagements and increase diversity in STI, enabling greater involvement of those with care responsibilities or located in more remote areas. Savings from reduced office space could also provide more resources for innovation activities but may also be used in other ways.
- More **scientific conferences, training and research collaboration activities may be held virtually**, with uncertain outcomes on the productivity of STI. Virtual conferences allow for larger and more diverse audiences than in-person meetings, and reduce transaction costs as well as the carbon footprint incurred by travel. Virtual training tools facilitate access to training for wider audiences and are highly flexible, making training more compatible with work commitments. They could also facilitate more tailored training by pooling expertise across institutions and enabling students to participate remotely in training offered by partner institutions.

However, there are **downsides to these applications**. Virtual environments are not perfect substitutes for face-to-face interactions, as building trusted relations for future research collaborations is harder. They also pose a challenge for newcomers: while virtual scientific events can easily recruit leading scholars to intervene, it can be more difficult for others to engage and make their mark. The transition towards hybrid modes of operation (i.e. where some participants are able to join in person while others join virtually) requires careful design to succeed.

At the same time, preparing for a long-lasting COVID-19 crisis or other future shocks may **accelerate the automation and business adoption of other technologies and practices**. The COVID-19 shock could also stimulate investments in the Internet of Things (IoT) and blockchain technologies to help increase the transparency of, and trust in, supply chains. Moreover, the fear of possible trade barriers and reshoring production to locations where labour is expensive may further contribute to the automation of processes. If a trend of reverse globalisation develops, more innovation investments could be devoted to improving the cost-efficiency of 3D printing or other digital technologies.

In this context, increasing **digital security and privacy** will be critical. Remote work during COVID-19 made systems more vulnerable to cyber-attacks (OECD, 2020[7]; OECD, 2020[8]). Online scams and phishing emails have proliferated, and cybercriminals have launched ransomware attacks against hospitals, research centres and critical infrastructure. Such risks increase incentives to accelerate the implementation of cybersecurity practices across organisations, and encourage investments in the development of related technology.

The **capacity and speed of digital technology adoption**, however, is asymmetric across actors. Limitations in access to infrastructure and skills, together with limited financial resources to invest in digitalisation processes, could constrain adoption, particularly among small and medium enterprises (SMEs) and micro-firms.

The openness and agility of STI systems

The rapid implementation of **open science and open data initiatives** during the COVID-19 crisis – including platforms to share research data, open access to COVID-19-related publications, and the early dissemination of research manuscripts as preprints – may prove to be a catalyst for the wider adoption of open science across all scientific research fields (OECD, 2020[9]). These practices enhance transparency and collaboration, reduce the risk of duplicated research efforts, and foster research and innovation built on the existing research base.

But a number of well-known challenges will need to be addressed, including making data sufficiently accessible (also across borders), interoperable and reusable (FAIR). This requires **standards on data sharing for research**, as several organisations have recognised. In October 2020, the National Institutes of Health (NIH) released a new policy for data management and sharing for all NIH-funded research (Wolinetz, 2020[10]). In January 2021, the OECD Council adopted a revised recommendation aimed at enhancing global access to research data and other research-relevant digital products from public funding (OECD, 2021[11]). There are also insufficient **incentives for scientists** to embrace open science principles. Currently, neither good data management nor the development of high-quality, reusable data sets are incentivised or rewarded, and data managers face unclear career paths in an academic research system that mainly rewards publication in scientific journals. Career advancement mechanisms partly based on metrics that account for open science or data-sharing efforts could enhance incentives in this regard. The costs involved in extending open science models (e.g. the costs of publishing and maintaining databases) need to be considered, as well.

Efforts undertaken to rapidly mobilise the STI community in response to the pandemic may boost **the agility of STI systems**. Changes could include reduced regulatory barriers for health innovations (e.g. more rapid vaccine approval processes) and quicker ways to publish research findings (e.g. wider use of preprints). A number of policy approaches that provided agile responses to the crisis could be used in the future, as well. These include the organisation of fast-track open competitions and hackathons to stimulate out-of-the-box thinking; matchmaking activities to accelerate the time between idea generation and commercialisation; and initiatives to facilitate open access to research infrastructures to accelerate research (Paunov and Planes-Satorra, 2021[3]).

The inclusiveness of STI systems

The COVID-19 crisis creates opportunities and challenges for the **social inclusiveness** of STI systems – defined as the extent to which individuals, independent of their socio-economic background, gender, age, ethnic origin, religion or place of residence, have the capacity and opportunity to participate in R&D and innovation activities, and to benefit from R&D and innovation.

- The prominence STI gained during the **COVID-19 crisis offers opportunities for greater inclusion**. More students may be attracted to pursue scientific career paths after the pandemic, including those from groups that have been historically underrepresented, such as women and minorities. The crisis has also allowed for large-scale experimentation with remote working. If such arrangements become more common among the STI workforce after the crisis, they may increase the involvement of women with young children, and allow those located in remote areas to engage in research and innovation networks. The consolidation of policy instruments used during the crisis, such as crowdsourcing challenges and hackathons, may also result in more diverse participation in innovation activities.

- On the other hand, the **crisis could exacerbate unequal participation in STI systems**. The extensive closures of education facilities during the pandemic pose a particular threat to students from disadvantaged groups, potentially reducing their opportunity to engage in STI careers over the next decade. The COVID-19 crisis may also result in the permanent exclusion of disadvantaged groups. Women researchers – especially those with young children and with elderly care responsibilities – were found to devote less time to research activities during lockdown, and it may not be easy for them to reconnect following the crisis. These lost years of career development may put a permanent limit on their advancement, which would only widen gender disparities in research careers. Young researchers, including PhD students and postdocs, may also face more challenges to enter the STI workforce under stable conditions, though differences are likely to emerge across scientific fields. Limited opportunities to "make a mark" may affect publishing opportunities, thereby reducing future career opportunities for researchers outside of top institutions.

The pandemic's **unequal effects across and within sectors** may exacerbate the gap in future innovation performance between the firms that thrived during the pandemic (e.g. large digital technology firms) and those that were most severely hit, more liquidity-constrained and less able to benefit from digital tools. In this regard, SMEs are more vulnerable than their larger counterparts. The withdrawal or tightening of support policies, and/or a tightening of credit conditions, could set off a wave of SME bankruptcies that have been thus far deferred. Unequal effects across and within sectors may affect the degree of market concentration and consequently future innovation dynamics (Guellec and Paunov, 2018[12]).

The longer-term **impact of the crisis on innovation performance will differ across cities and regions**, depending on their exposure to global value chains and their reliance on heavily hit sectors such as tourism, potentially widening gaps in innovation performance across regions. The large-scale adoption of remote working, however, could reduce the advantages of agglomeration economies and push towards a more evenly spread distribution of innovation activities across regions. Some regions, such as Emilia Romagna in Italy, have already adopted policies to attract remote workers. The possible pushback against globalisation, and the incentive to reduce concentration of the global production of certain products in order to increase systems' resilience, may also create new opportunities for building more diversified economies, and support different regions' efforts to contribute to this objective.

The **pandemic also risks widening disparities at the global level**. World Bank estimates (as of January 2021) suggest that the COVID-19 crisis pushed more than 119 million people into extreme poverty in 2020, with the largest share of "new poor" in developing countries (Lakner et al., 2020[13]). The global economic downturn could slow down or even reverse recent advances in economic development in low- and middle-income countries, possibly hindering capacity-building efforts needed to engage in international research and innovation networks. Disruptions to schooling, which on average have been longer in developing countries, could erode earlier gains in human capital development. Expanded investments in digital and virtual learning during the COVID-19 pandemic could help address the loss if it results in the provision of low-cost high quality education (OECD, 2021[14]).

The global nature of STI systems

The COVID-19 crisis has both challenged international collaboration and demonstrated its importance in tackling global challenges. Going forward, **opportunities and policy support for international co-operation may be reinforced** in an effort to optimise an efficient global STI system that benefits from national specialisations and capacities, especially in the health field. For instance, emphasis may be placed on building strong international platforms to share data about infectious diseases, launch international funding schemes for research and development of vaccines and treatments for emerging diseases, or establish a global disease prevention and control system.

Incentives for international collaboration may be reduced, however, by public budget constraints stemming from the crisis, restrictions on international mobility, and countries' concerns over building

national technological capacities in view of possible future shocks and geopolitical tensions. Countries may also decide to direct efforts at building strategic alliances with certain countries at the expense of global collaborative initiatives. This could involve, for instance, investments to ensure national or regional self-sufficiency in the production of essential goods (such as food and health supplies) to avoid shortages similar to those experienced with key medical equipment during the first months of COVID-19. The crisis may also amplify demands for access to key technologies, such as 5G communications and AI, in view of concerns over national security, the risk of future dependencies on foreign technology suppliers, and concerns over global monopolies and their potentially detrimental effect on technological progress.

Policy implications

Possible changes in future STI policy objectives

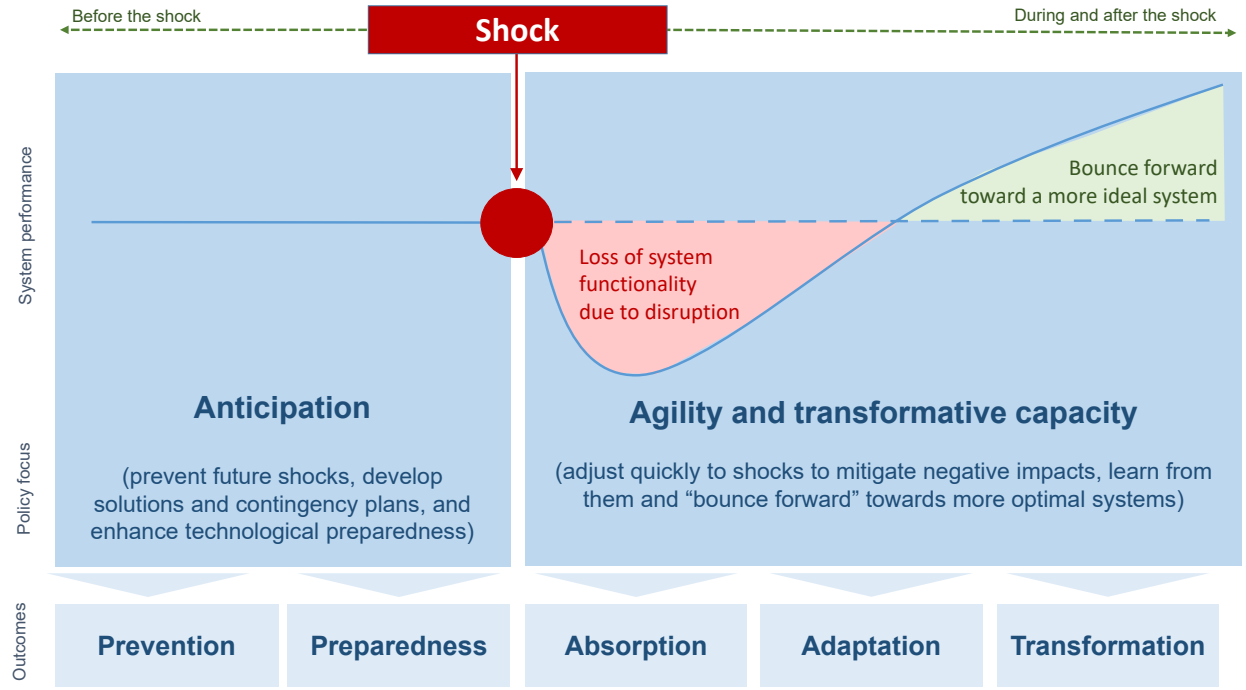
The COVID-19 crisis may change the role of STI policy in the recovery, as countries seek to "build back better". If **resilience, environmental sustainability and inclusiveness** emerge as core objectives on policy agendas, STI policy could play a significantly different role than it has in previous decades, when it was primarily evaluated according to its contributions to productivity and competiveness for long-term growth. The recent expansion of mission-oriented research and innovation policies (MOIP) already signals a policy shift towards **increased directionality of STI policies** – a trend that may be reinforced after the COVID-19 crisis (Larrue, 2021[15]).

STI can play a larger role in building a more environmentally sustainable, inclusive and resilient future. Greening principles have been **integrated as part of the massive recovery packages** implemented to support economic recovery. In November 2020, for instance, the UK Government announced a GBP 12 billion (USD 17 billion) ten-point green recovery plan that includes investments in innovative green technologies and support for industry (including the transportation, energy and construction sectors) to decarbonise. Similarly, recovery programmes can support STI that steers towards more resilience and inclusiveness. Previous STI policies implemented to support green and inclusive growth can provide critical insights for designing policies for the recovery (Borowiecki et al., 2019[16]; Planes-Satorra and Paunov, 2017[17]).

Building resilience to crises has become a new policy priority. STI can contribute to two dimensions of resilience (Figure 1). The first is anticipation, which involves developing solutions to prevent and improve preparedness for future crises, such as pandemics and shocks related to climate change or cyberattacks. The second is agility and responsiveness to shocks – i.e. the capacity to adjust quickly in the event of a shock in order to mitigate its negative impacts and seize emerging opportunities. Innovation systems that respond most effectively to shocks are characterised by a strong scientific base, a vibrant and innovative business sector, and fluid interactions between both industry and science and across international research and innovation networks. The various possible changes generated by COVID-19 could affect these dimensions of STI systems and consequently their resilience.

Crafting STI policy for a more inclusive, resilient and sustainable future **requires understanding complementarities and trade-offs** between these objectives and growth in the recovery. Determining priority fields – i.e. research/technology areas, sectors or missions – for STI policy support also requires careful consideration: if the absolute amount of funding for STI is not increased, providing more support to new priority fields reduces the funding for others. Moreover, operationalising a new set of policy goals requires developing metrics and lead indicators, particularly on resilience. The latter could include indicators that measure how diversified the supply of essential goods is.

Figure 1. Dimensions of systems' resilience



Source: Authors' elaboration based on Hynes et al. (2020[18]), "Bouncing forward: a resilience approach to dealing with COVID-19 and future systemic shocks", http://dx.doi.org/10.1007/s10669-020-09776-x.

New data, tools and policy approaches shaping the evidence base for, and governance of, STI policy

New tools for STI policy may gain greater importance following the unprecedented use of **real-time granular data** (e.g. mobility data, pulse surveys) and **big data visualisation and analysis tools** during the pandemic. These may, in turn, render STI policy responses more agile, targeted and ultimately more effective.

Unconventional policy approaches could gain ground over the coming years, including approaches that embed **strategic foresight** within policy making, i.e. the structured and explicit exploration of multiple futures in order to inform decision making. **Systems approaches**, which account for interconnections in socio-economic processes, aim to formulate policies based on their impacts on the entire system rather than on a single component or process. When it comes to advancing the transition towards green mobility, for instance, this requires investing in relevant R&D, adapting city infrastructures, establishing efficient public transportation services and increasing public awareness about its benefits.

Reflections on **new governance models** involving intergovernmental co-operation and relations with the media will also figure in revisited STI policy agendas. The wider engagement of civil society institutions in STI policy may also be further embraced, particularly in view of achieving important societal transformations.

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