5 Resolving global challenges and crises through international collaboration

Collaboration lies at the heart of the science, technology and innovation (STI) response to COVID-19, where national and international collaborative platforms for technology are revolutionising vaccine design and production. The chapter argues that policy makers should capitalise on the momentum from the international community's response to COVID-19 to re-focus international STI co-operation on global public goods problems through greater transdisciplinary research, new public-private funding mechanisms, and stronger collaborative innovation models.

Key findings

- **The development of vaccine candidates has been exceptionally rapid and has drawn on nascent global R&D preparedness measures**, including support for novel platform technologies that are revolutionising vaccine design and production, and the 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.
- **The concerted response to COVID-19 offers renewed hope that international STI co-operation can help provide solutions to other global challenges**. However, this will require reinforcing a new paradigm of international STI co-operation that places more value on challenge-driven, transdisciplinary research. In particular, governments need to work together on new financing and governance mechanisms, wherein business and private-finance actors coordinate with multilateral and national development banks to co-finance STI solutions for global challenges.
- **Government responses to the COVID-19 pandemic highlight the importance of national politics, leadership and values in influencing international STI co-operation**. Governments will need to balance national STI priorities and goals with the need for internationally co-ordinated action to address grand challenges and global public goods problems. Without such collective action, the capacities to deal with them – in the form of scientific knowledge, technology platforms and international co-ordinating institutions – will remain underdeveloped, leaving countries more exposed to global shocks. At the same time, governments need to build trust and define common and shared values to ensure a level playing field for scientific co-operation and an equitable distribution of benefits.

Introduction

The science and innovation response to COVID-19 has been a largely international effort, reflecting the steady growth of international science, technology and innovation (STI) collaboration in recent decades.[1] Much STI collaboration on COVID-19 is "bottom-up", initiated by scientists themselves. But the challenges posed by a pandemic also call for more orchestrated responses at an international level, in order to share data, identify and fill knowledge gaps, exploit complementarities and pool resources. These increasingly involve not only governments, but also businesses, philanthropies and civil society actors. Ideally, such responses should be truly global, but in their absence, bilateral and regional approaches may offer opportunities for "coalitions of the willing" to move forward, including the participation of low- and middle-income countries, many of whom bear the brunt of the worst effects of global challenges.

Public-private partnerships have proliferated in response to COVID-19, mobilising public researchers, businesses, governments and philanthropic organisations from around the world to work together on developing various countermeasures, notably vaccines, therapeutics and diagnostics. The World Health Organization (WHO) plays a convening role in many of these efforts, while various specialised global research partnerships co-ordinate and implement research and finance initiatives, most visibly in pursuit of COVID-19 vaccines. These partnerships – most of which were established in recent years in the wake of infectious disease outbreaks like Ebola – are well-regarded and are making significant contributions to the development and equitable distribution of vaccines through international co-operation. Crucially, they have been able to draw on recent global research and development (R&D) preparedness measures, including support for novel platform technologies that are set to revolutionise vaccine design and production.

The international response to COVID-19, although not free of difficulties, offers renewed hope that international STI co-operation can help provide solutions to other global challenges. Societal or grand challenges, such as climate change, food security and public health issues, are increasingly targeted by international STI co-operation, mirroring their adoption as priorities in national policies. The Sustainable Development Goals (SDGs) in particular have become a significant focus, with ongoing efforts to translate them into national and international research priorities supported by funding bodies. Targeting STI collaborative efforts on global challenges and issues related to global public goods (GPGs) will, however, require a paradigm shift in the priorities and practices of much existing STI co-operation. For instance, greater use of "blended finance" could support collaborative STI projects directed at the SDGs, pooling funding from governments, business, philanthropists and the financial community. Overall, the joint mobilisation of science, industry, government and civil society at a global level will be essential to trigger the deep transformations required to tackle challenges like the climate emergency.

Stepping up collaboration to fight COVID-19

Collaboration has been a hallmark of STI responses to the pandemic crisis

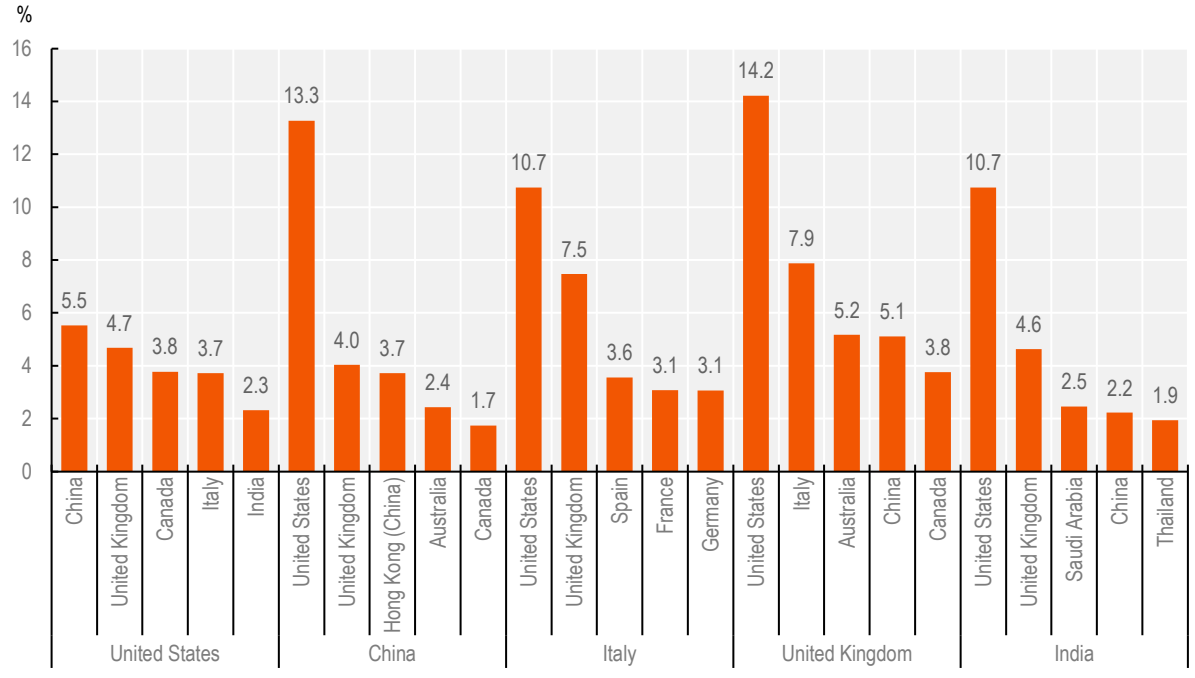
International scientific co-operation on COVID-19 started through exchanges of data and genetic and viral material, originally from China to other research centres across the world, marking a relatively rapid development compared to previous pandemics. Less than 24 hours had elapsed between the sequencing of the first coronaviruses by the Chinese public health laboratories to full genome data being publicly shared on the Global Initiative on Sharing Avian Influenza Data (GISAID) EpiCoV™ database,[2] a public-private-partnership. Since then, numerous international open data-sharing platforms have sprung up to provide access to epidemiological, clinical and genomics data, as well as related studies. Protocols and standards used to collect the data are also being shared, together with analytical tools. The COVID-19 Open Research Dataset (CORD-19), created by the Allen Institute for AI in collaboration with the US government and a number of firms, foundations and publishers, contains more than 280 000 full-text

machine-readable scholarly articles on COVID-19 and related coronaviruses, and serves as a basis for applying machine-learning techniques to generate new insights supporting COVID-19 research. Other initiatives include repositories of genome data (such as Nextstrain and GISAID), chemical-structure data (e.g. CAS COVID-19 antiviral candidate compounds dataset), clinical studies (e.g. ClinicalTrials.org for COVID-19-related studies) and data for modelling research (e.g. MIDAS). The European Commission launched the COVID-19 Data Portal in April 2020 to bring together relevant datasets for sharing and analysis in an effort to accelerate coronavirus research. It enables researchers to upload, access and analyse COVID-19 related reference data and specialist datasets as part of the wider European COVID-19 Data Platform.[3] Most scientific journal publishers have waived traditional access costs related to scientific articles on COVID-19 (OECD, 2020[1]).

As highlighted in Chapter 2, there continues to be an impressive output of scientific articles on COVID-19. OECD analysis of PubMed data shows that the United States and China are the two largest contributors to COVID-19 publications[4] (see Chapter 1), and are also one another's main collaborating partner (Figure 5.1). Other research confirms these patterns. For instance, an analysis by (Fry et al., 2020[2]) of all scientific articles on coronaviruses published from 1 January 2018 until 8 April 2020 found that the United States and China increased their collaboration in the wake of the COVID-19 outbreak.

Figure 5.1. Share of international scientific collaboration on COVID-19 medical research by partner economy

Top five economies, in terms of total number of documents (fractional counts), and their top 5 partner economies, from 1 January to 30 November 2020

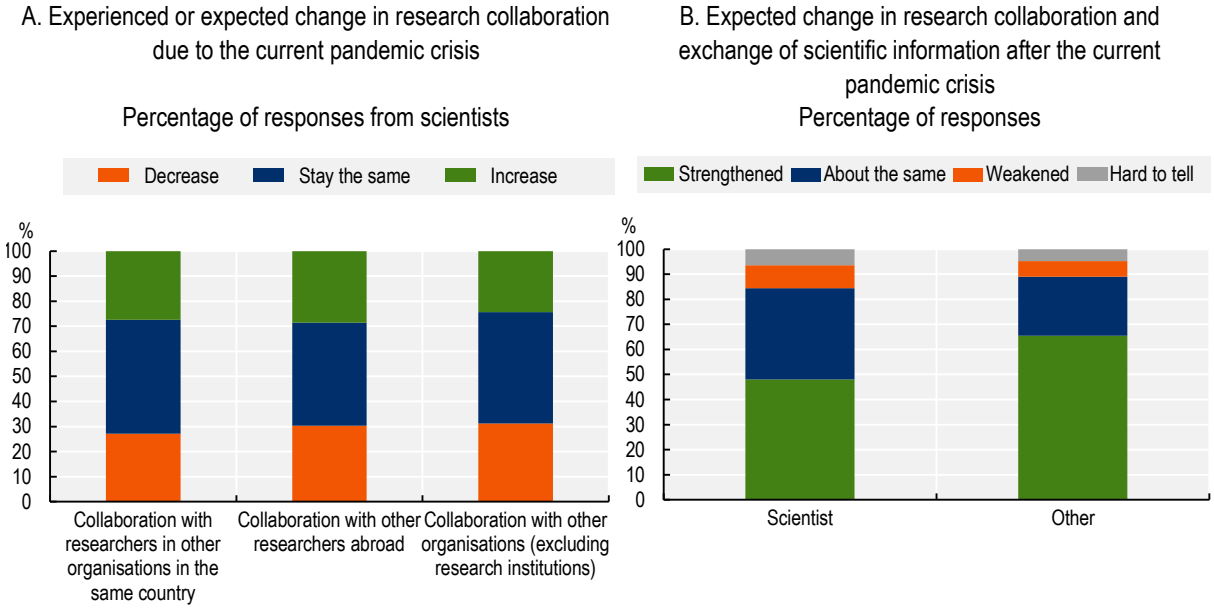


Note: The period covers 1 January to 30 November 2020 and includes 74 115 documents. The United States co-authored 16 964 documents. 84% of those were domestic co-authorships, while the remainder involved international collaboration. The top collaboration partner of the United States is China, and US-China collaboration represents 5.5% of all United States publications on COVID-19-related medical research.
Source: OECD and OCTS-OEI calculations, based on US National Institutes of Health (NIH) PubMed data, https://pubmed.ncbi.nlm.nih.gov/ (accessed 30 November 2020).

StatLink https://doi.org/10.1787/888934223479

When asked in the ongoing OECD Science Flash Survey 2020 about their experiences and expectations of research collaboration during the pandemic crisis, scientists are more or less evenly split as to whether they have experienced an increase or decrease in collaboration Figure 5.2, Panel A). However, almost half expect enhanced research collaboration and exchange of scientific information after the current pandemic crisis, while less than 10% expect weakened collaboration (Figure 5.2, Panel B).

Figure 5.2. Scientists' experiences and expectations of research collaboration during the crisis



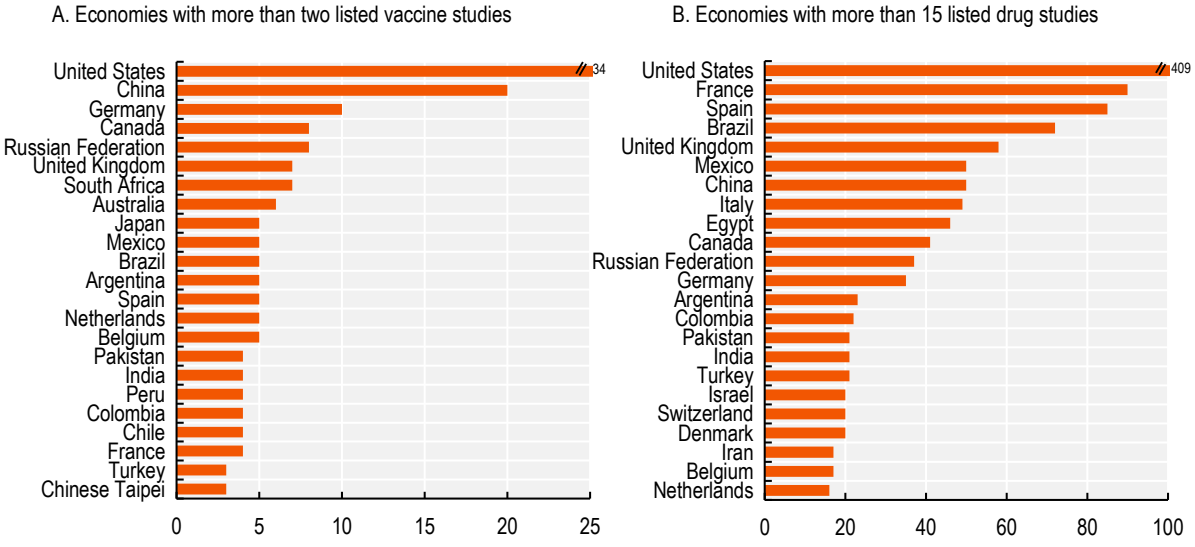
Note: For Panel A, respondents were asked, "As a result of the current crisis, have you personally experienced or do you expect to experience a change in (i) collaboration with researchers in other organisations in the same country; (ii) collaboration with other researchers abroad; and (iii) collaboration with other organisations (excluding research institutions)?" For Panel B, respondents were asked, "How do you expect the world of science to emerge out of the current crisis, in terms of collaboration and exchange of scientific information?"
Source: OECD Science Flash Survey 2020, https://oecdsciencesurveys.github.io/2020flashsciencecovid/ (accessed 12 October 2020).

StatLink https://doi.org/10.1787/888934223498

Collaborations on clinical research and clinical trials on COVID-19 have also grown significantly. Hundreds of clinical trials have been registered since early 2020, most of them to test drug candidates, but also several vaccine candidates. Figure 5.3 shows the number of COVID-19 studies registered on the NIH's portal ClinicalTrials.gov by 8 December 2020. The United States accounts for the largest number of clinical trials by far, particularly for drugs. China comes second on vaccine trials. Based on data from BioMedTracker and Pharmaprojects, two online platforms that track drug development, Bryan, Lemus and Marshall (2020[3]) found that 40% of drug therapies for COVID-19 were being developed by teams of firms (significantly higher than 21% for H1N1 influenza virus therapies, 9% for Ebola and 11% for Zika). They also found that about one-third of these collaborations are new.

Figure 5.3. Registered COVID-19 vaccine and drug studies by economy

Number of COVID-19 studies, 1 January to 8 December, 2020



Note: The charts show the number of COVID-19 studies registered at the NIH's ClinicalTrials.gov. The International Committee of Medical Journal Editors requires trial registration as a condition for publishing research results generated by a clinical trial. Multi-economy registered studies are counted in each economy. Note that the number of studies is not necessarily indicative of the breadth or depth of the studies conducted within each territory. Iran stands for Islamic Republic of Iran.
Source: United States National Institutes of Health, https://clinicaltrials.gov, (accessed 8 December 2020).

StatLink https://doi.org/10.1787/888934223517

Public-private partnerships are at the heart of COVID-19 countermeasures

Public-private partnerships (often involving several firms) are playing central roles in the fight against COVID-19. For example, the United States had allocated, through its Operation Warp Speed (OWS), more than USD 11 billion by October 2020 among more than 40 companies to fund the development of vaccines, diagnostics, therapeutics and other rapidly deployable capabilities. In parallel (and under the umbrella of OWS), the NIH is funding a public-private partnership to prioritise and accelerate development of the most promising COVID-19 treatments and vaccines (Box 5.1). Much of the funding from OWS is intended to deal with market failures associated with vaccine development and production. Many other countries have used similar rationales to fund vaccine and therapeutics research, though on a smaller scale. For example, Germany has committed around EUR 750 million to accelerate vaccine R&D through a special programme targeting three companies to set up their projects more broadly and to progress more quickly.[5] At a multilateral level, COVAX is another public-private partnership that has been playing a crucial role in vaccine development while paying special attention to the needs of low- and middle-income countries (Box 5.3).

All of these initiatives have some strategic features in common. Besides R&D, they invest in manufacturing capacity, advanced market commitments, and liability limitations, reducing uncertainties for the private sector to become involved. Moreover, to avoid delays between regulatory approval and the rolling out of vaccines, many of the activities that usually occur after completion of the R&D and marketing authorisation stages are being executed in parallel, with the result that manufacturing of some vaccines started while they were still in clinical trials. This fast track is intended to ensure a sufficient number of doses are globally available (by the end of 2021) once regulators grant their approval.

Box 5.1. US public-private partnerships for COVID-19 countermeasures

Overall, because of their scale and scope, US investments in basic and applied research and in clinical trials are providing a major boost to global efforts to develop COVID-19 vaccines and therapeutics

Operation Warp Speed (OWS)

The goal of OWS is to produce and deliver 300 million doses of safe and effective vaccines, with initial doses available by January 2021, as part of a broader strategy to accelerate the development, manufacturing and distribution of COVID-19 vaccines, therapeutics and diagnostics (collectively known as countermeasures). By early October 2020, OWS had invested more than USD 11 billion into seven vaccine candidates, with funding coming from the United States Congress, including through the Coronavirus Aid, Relief, and Economic Security Act (the CARES Act). To accelerate development while maintaining safety and efficacy standards, OWS has been selecting the most promising countermeasure candidates and providing co-ordinated government support. Protocols for demonstrating safety and efficacy are being aligned, allowing trials to proceed more quickly. The protocols for the trials are overseen by the federal government. Rather than eliminating steps from traditional development timelines, these are proceeding simultaneously, such that manufacturing of a promising vaccine at an industrial scale can start well before the complete demonstration of its efficacy and safety, which would normally be required. The federal government is making investments in the necessary manufacturing capacity at its own risk, giving firms confidence that they can invest aggressively in development, and allowing faster distribution of an eventual vaccine. The manufacturing capacity developed will be used for whatever vaccine is eventually successful, regardless of which firms have developed the capacity. OWS is a partnership among components of the Department of Health and Human Services that engage with private firms and other federal agencies.

National Institutes of Health – Accelerating COVID-19 Therapeutic Interventions and Vaccines (ACTIV)

Announced in April 2020, ACTIV is a public-private partnership headed by the NIH to develop a co-ordinated research strategy for prioritising and accelerating development of the most promising treatments and vaccines. It acts, for example, by streamlining clinical trials, co-ordinating regulatory processes and/or leveraging assets among all partners to rapidly respond to COVID-19. Co-ordinated by the Foundation for the National Institutes of Health, ACTIV brings the NIH together with its sibling agencies in the Department of Health and Human Services, other government agencies, OWS, the European Medicines Agency, representatives from academia, philanthropic organisations (including the Bill & Melinda Gates Foundation and the Fred Hutchinson Cancer Research Center), and 20 biopharmaceutical companies.[6]

Sources: OWS website: https://www.hhs.gov/coronavirus/explaining-operation-warp-speed/index.html (accessed 16 October 2020); NIH ACTIV website: https://www.nih.gov/research-training/medical-research-initiatives/activ (accessed 16 October 2020).

STI co-operation supporting timely and globally equitable solutions to COVID-19

Identifying and developing appropriate and viable COVID-19 tests, treatments and vaccines require large investments with a high level of risk. This means countries need to pool their investments globally. In this regard, the WHO is playing a lead convening role in formulating STI responses to COVID-19 (see Box 5.2). It has published an R&D Roadmap for COVID-19, and is a partner in the influential Access to COVID-19 Tools (ACT) Accelerator, a global collaboration to accelerate development, production, and equitable access to COVID-19 tests, treatments, and vaccines (see Box 5.3).

Building on the philosophy that no single country can beat COVID-19 on its own, the ACT-Accelerator works to shape the market for solutions and incentivise manufacturers to invest in developing and manufacturing their supply. The ACT-Accelerator also offers governments access to a portfolio of solutions that spread the risk of failure of individual treatment or vaccine candidates, as well as other solutions (across multiple geographies and multiple technical platforms) should one of them prove not to be viable (WHO, 2020[4]). The ACT-Accelerator is organised into four pillars of work, led by different organisations. The most prominent is the vaccine pillar, known as COVAX (see Box 5.3), which is led by the Coalition for Epidemic Preparedness Innovation (CEPI) and the Global Alliance for Vaccines and Immunizations (GAVI). As outlined in Box 5.2, CEPI funds R&D and up-scaling processes into a diverse portfolio of COVID-19 vaccine candidates, while GAVI focuses on the procurement and allocation of vaccines.

Box 5.2. Selected key organisations supporting international STI collaboration on COVID-19

World Health Organization (WHO)

The WHO is leading the international response to the COVID-19 pandemic. It has published an R&D Roadmap for COVID-19 and established the ACT-Accelerator with the assistance of Global Research Collaboration for Infectious Disease Preparedness (GloPID-R), an international network of research-funding organisations. The ACT-Accelerator brings together governments, the private sector, philanthropic entities and other international organisations to accelerate development, production and equitable access to COVID-19 tests, treatments and vaccines. The WHO also set up the Solidarity Trial to facilitate the robust worldwide comparison of unproven treatments for COVID-19. Box 5.3 provides more details on these and other initiatives.

Coalition for Epidemic Preparedness Innovation (CEPI)

Established in 2017, CEPI is a global partnership between public, private, philanthropic and civil society organisations that aims to accelerate the development of vaccines (based on the WHO R&D Blueprint of emerging infectious pathogens) and enable equitable access to these vaccines for affected populations during outbreaks. CEPI takes an end-to-end approach, operating as both a funder and a facilitator. It focuses on vaccine development, licensure and manufacturing while supporting the efforts of vaccine discovery and delivery. Among its tasks, it funds new and innovative platform technologies with the potential to accelerate the development and manufacture of vaccines against previously unknown pathogens, the so-called “Disease X” from the WHO Blueprint. Based on platform technology work and funded research on Middle East Respiratory Syndrome (MERS), CEPI was able to quickly start building up a COVID-19 vaccine R&D portfolio in January 2020. CEPI has been expanding its COVID-19 work and is currently funding R&D for nine different vaccine candidates with the aim of providing up to 2 billion vaccine doses by the end of 2021.

Global Alliance for Vaccines and Immunizations (GAVI)

Created in 2000, GAVI is an international organisation that brings together the public, private and philanthropic sectors with the shared goal of creating equal access to new and underused vaccines for children living in the world’s poorest countries. It does this by creating robust markets for vaccines and other immunisation products, thereby allowing manufacturers to plan production based on known demand, and low- and middle-income countries to buy suitable products at prices they can afford. With the support of CEPI and the WHO, GAVI is responsible for administering the COVAX facility, described in Box 5.3.

Global Research Collaboration for Infectious Disease Preparedness (GloPID-R)

GloPID-R is an international network of research-funding organisations. It was launched in 2013 by the heads of international research organisations to facilitate, accelerate and deepen collaboration among research funders on emerging diseases by investing to strengthen global research preparedness between crises, and mobilising resources to respond rapidly and effectively to significant infectious disease outbreaks. In the COVID-19 context, GloPID-R has convened working groups on priority research, together with the UK Collaborative on Development Research. It has also created an online database of funded research projects mapped to the WHO R&D Roadmap. The European Commission finances the GloPID-R Secretariat, which is split between the Mérieux Foundation and the University of Oxford.

Sources: WHO website, https://www.who.int/; CEPI website, https://cepi.net/; GAVI website, https://www.gavi.org/; GloPID-R website, https://www.glopid-r.org/ (accessed 16 October, 2020).

Box 5.3. Main international collaborative initiatives

WHO R&D Blueprint

Following the Ebola outbreak in West Africa, the WHO drew up in 2016 a global strategy and preparedness plan. Known as the R&D Blueprint, the plan aims to support the rapid activation of R&D activities during epidemics[7] and fast-track the availability of effective tests, vaccines and medicines. The WHO uses the R&D Blueprint to convene a broad global coalition of experts from medical, scientific and regulatory backgrounds to work on a given priority disease, leading to the creation of an R&D roadmap for that disease. The R&D roadmap is then used to guide the response to outbreaks through both urgent actions and developing ways to improve the global response for future epidemics. As part of the WHO's response to COVID-19, the R&D Blueprint was activated to accelerate diagnostics, vaccines and therapeutics for the new virus. In collaboration with GloPID-R, in February 2020 the WHO organised a global forum on research and innovation for COVID-19 where experts identified key knowledge gaps and research priorities. The WHO published its resulting R&D Roadmap for COVID-19 in March 2020, outlining immediate, mid-term and longer-term priorities to build a robust global research response to the crisis.

WHO Access to COVID-19 Tools (ACT) Accelerator

The ACT-Accelerator is a global collaboration to accelerate development, production and equitable access to COVID-19 diagnostics, therapeutics and vaccines. Launched in April 2020 and building on the commitment made by G20 leaders in March 2020 to the Coronavirus Global Response, the ACT-Accelerator is a framework for collaboration, rather than a decision-making body or new organisation. It is organised into four pillars of work – diagnostics, treatment, vaccines and health system strengthening – led by a range of collaborating organisations, including the Bill & Melinda Gates Foundation; CEPI; GAVI; the Global Fund to fight AIDS, Tuberculosis and Malaria; Unitaid; the Foundation for Innovative New Diagnostics; the Wellcome Trust; the World Bank; and the WHO. The ACT-Accelerator has ambitious targets: it aims to provide 245 million courses of treatment and 500 million diagnostic tests to low- and middle-income countries in 2021, and 2 billion vaccine doses to the world by the end of 2021.

COVAX

COVAX is one of the four pillars of the ACT-Accelerator, dedicated to advancing the work on vaccine development, manufacturing, procurement and delivery at scale, as well as policy and allocation. COVAX enables risky investments in production capacity across several vaccine candidates to ensure that doses can be made immediately available at scale upon regulatory approval. COVAX combines the power and expertise of CEPI's R&D role on the "push side" with GAVI's procurement and allocation function on the "pull side", e.g. through the COVAX AMC. Through portfolio diversification, pooling of financial and scientific resources, and economies of scale, participating governments and blocs[8] can hedge the risk of backing unsuccessful candidates, just as governments with limited or no ability to finance their own bilateral procurement can be assured of access to life-saving vaccines that would otherwise have been beyond their reach.

WHO Solidarity Trial

Solidarity is an international clinical trial launched by the WHO and partner organisations to help find an effective treatment for COVID-19. It is one of the largest international randomised trials for COVID-19 treatments, enrolling almost 12 000 patients in 500 hospital sites in over 30 countries. Enrolling patients in a single randomised trial helps facilitate the robust worldwide comparison of unproven treatments, overcoming the risk of multiple small trials not generating the strong evidence needed to determine the relative effectiveness of potential treatments.

Sources: WHO R&D Blueprint website, https://www.who.int/publications/m/item/a-coordinated-global-research-roadmap (accessed 25 October 2020); ACT-Accelerator website, https://www.who.int/initiatives/act-accelerator; COVAX website, https://www.who.int/initiatives/act-accelerator/covax; WHO Solidarity Trial website, https://www.who.int/emergencies/diseases/novel-coronavirus-2019/global-research-on-novel-coronavirus-2019-ncov/solidarity-clinical-trial-for-covid-19-treatments. All accessed 16 October 2020.

Health systems will need to vaccinate 50% to 75% of the global population to end the pandemic. This requires building manufacturing and distribution capacity, ensuring a new vaccine is affordable, deciding who should get access first and planning massive vaccination campaigns at a global scale. Vaccines have been described as GPGs, but this will not be the case initially with COVID-19 vaccines, since their limited supply will mean they are neither non-excludable or non-rival (Bollyky and Bown, 2020[5]). Several countries, as well as the European Union, have concluded advanced purchase agreements with COVID-19 vaccine manufacturers. More than 10 billion doses of COVID-19 vaccines had been pre-ordered by late-2020, accounting for most of the manufacturing capacity for the leading vaccine candidates in 2021. High-income countries bought up broad portfolios of products early in the pandemic, placing bets on a number of candidates. Canada, the United States, the United Kingdom, Australia and the European Union have each pre-ordered more than four doses of COVID-19 vaccines per person. Countries with excess doses could ultimately donate these to COVAX (Mullard, 2020[6]; Callaway, 2020[7]).

To avoid a situation where a small number of wealthy economies secure the global supply of vaccines only for themselves, COVAX has also signed advanced purchase agreements to secure manufacturing capacity and vaccine doses even before any vaccines were licensed. COVAX aims for affordable, fair and equitable access to safe and effective COVID-19 vaccines for all. More than 180 countries and economies are now involved,[9] including 92 low-income economies that would otherwise be unable to afford these vaccines and will be supported through an advanced market commitment (AMC).[10] To gain access to 1 billion doses for AMC-eligible economies, GAVI's COVAX AMC has set an initial fundraising goal of USD 2 billion by the end of 2020 to reserve and accelerate the production of doses. Already by October 2020, GAVI had reached USD 1.8 billion in contributions and pledges from sovereign donors, the private sector and philanthropic sources.[11] At least USD 5 billion more will be needed in 2021 to procure doses as they come through the portfolio.

COVAX also provides direct protection for countries that already have their own bilateral deals with vaccine manufacturers by increasing their chances of securing safe and efficacious vaccine doses, given that not all candidates will ultimately be successful. COVAX also offers indirect protection by covering low-income countries that would otherwise be unable to afford these vaccines, thereby reducing the chances of a COVID-19 resurgence in their territories that could quickly spread across the globe (WHO, 2020[8]). Accordingly, most OECD countries are now members of COVAX.

The essential roles of global R&D preparedness

Development of vaccine candidates has been exceptionally rapid. Hundreds of vaccines are currently in development across the world; three had announced Phase 3 clinical trials results by the end of November 2020; and one had already gained regulatory approval in several jurisdictions by early-December and was being administered to vulnerable groups. This scale, combined with the scope of utilising a range of different technology platforms, increases the chances of success. While most would agree that the world was ill-prepared for COVID-19, despite repeated warnings that a new pandemic was "a question of 'when', not 'if'" (Global Preparedness Monitoring Board, 2019[9]), certain steps – such as long-term commitments to basic research, as well as various technological and institutional innovations at the global level – had been undertaken in recent years to improve global R&D preparedness, and these appear to have paid off to some extent.

The WHO R&D Blueprint was an important cornerstone (Box 5.3), prioritising, accelerating and co-ordinating product-related R&D for epidemic risk diseases with no existing treatments. The diseases covered included the so-called "Disease X", caused by a hypothetical pathogen not yet known to infect humans. R&D funding for the pathogens listed on the WHO R&D Blueprint list was provided by CEPI, including a call for proposals for the development of platform technologies able to expedite some stages of clinical development and permit advance development of multiple vaccine candidates at the same time. Such technologies can also be extended to manufacturing, allowing progress in setting up production facilities before the targets of the upcoming vaccines are even decided (see Chapter 7). Platform technology approaches include DNA and messenger RNA vaccines, adjuvants, monoclonal antibodies and broad-spectrum antivirals (Hall, Jamieson and Wardle, 2019[10]; van Riel and de Wit, 2020[11]).

Its work on platform technologies enabled CEPI to respond very quickly to the outbreak at the end of January 2020. Within two weeks of the publication of the SARS-CoV-2 sequence, it was able to leverage and support several of its research partners to begin developing vaccines against the virus (WHO, 2020[8]). The existence of vaccine development partners for MERS, combined with readily available funding and established expertise, enabled the rapid roll-out of vaccine development for COVID-19, using an accelerated paradigm to conduct development and scale up activities in parallel. Major research groups and research-funding agencies had already switched their vaccine development strategies to invest in novel vaccine platforms for particular virus families, which also helped considerably (Keusch and Lurie, 2020[12]). With the ongoing approval of a first generation of vaccines, CEPI is establishing the 'Wave 2 Portfolio' of COVID-19 vaccine candidates, which aims to optimise the vaccines that are available in the longer term.[12]

CEPI is an example of a "collaborative platform", an emerging form of multisector partnership in which participants co-develop new technologies and processes with significant potential for advancing health and more resilient societies (OECD, forthcoming[13]). Collaborative platforms are convergence spaces that bring together a high diversity of stakeholders, disciplines, technologies and cultures. In the area of healthcare, they can optimise access to and use of information generated in research, clinical settings and markets for the benefit of patient care. They offer opportunities for experimentation in health innovation and de-risking research on emerging technologies, complex health challenges (e.g. dementia, antibiotic resistance and pandemics), and products with limited markets and potentially low returns on investment. The pooling of resources, competencies and complementary skills enables communication across sectors,

manages risks, offers access to infrastructure and drives technology translation. Besides CEPI, several other healthcare collaborative platforms are wholly committed to ensuring equitable access to research data and products related to COVID-19. These include the Joint European Disruption Initiative (JEDI) Billion Molecules against COVID-19 Grand Challenge, and the Research Investment for Global Health Technology Fund (The RIGHT Fund).

The momentum created by the pandemic offers opportunities to establish effective and sustainable global mechanisms to support the range and scope of R&D necessary to confront a wider range of potential health emergencies (Global Preparedness Monitoring Board, 2020[14]). For example, ACT-Accelerator and COVAX represent major innovations. They indicate that with effective global leadership, it is possible to support market commitments, procurements and the fair global allocation of vaccines (Keusch and Lurie, 2020[12]). They have also promoted the technological advancement of the tools they have invested in (WHO, 2020[4]). Collaborative responses to COVID-19 have also seen the emergence of an array of new intellectual property rights (IPR) agreements to support access to medicines, possibly laying the groundwork for new modalities of R&D on GPGs moving forward.

The crisis has also exposed several shortcomings that need to be addressed for STI collaboration to play its full role in building resilience, and addressing future crises and grand challenges.

- Despite its strong performance, CEPI was formed to deal with regional epidemics and lacks sufficient funding for a global pandemic response. Its funding derives from a mix of R&D funding and traditional development assistance that relies on a small number of generous countries and private foundations. There are calls to expand CEPI's funding base, drawing on national and regional health security budgets that have yet to be established. This would allow CEPI to become a lead actor in the context of global health security (Global Preparedness Monitoring Board, 2020[14]). Options like these will need to be discussed more broadly in the wider context of the lessons learnt from the current pandemic.
- GloPID-R was created with funder and research co-ordination in mind. However, because there was no ready pool of funding to draw on and country limitations with regard to speed were not fully anticipated at the outset, it has not been able to move as quickly as needed to respond to the pandemic (Keusch and Lurie, 2020[12]).
- While much attention has focused on COVID-19 vaccines, improving R&D preparedness for therapeutics may require a similar mechanism to CEPI and vaccines. Furthermore, despite the obvious need, little innovation has taken place over the last five years in novel platforms and technologies for diagnostic tests (Hall, Jamieson and Wardle, 2019[10]; Keusch and Lurie, 2020[12]).
- Rapid activation is a "cost of preparedness". This approach was taken by CEPI as part of its preparedness efforts with regards to vaccine development. Extending such an approach to diagnostics and therapeutics would require governments worldwide to rethink the concept of health security budgets and invest in the necessary infrastructure. One approach is that global funders agree on a reasonable, "no regrets" annual budget underpinning preparedness, and ensure those resources are always available and can be rapidly released (Keusch and Lurie, 2020[12]).
- Early research on COVID-19 was plagued by too much uncoordinated experimentation and a lack of adherence to shared standards on pre-clinical research, impeding the generation of robust evidence to underpin medical knowledge (OECD, 2020[15]). With so much development happening in parallel, organising clinical trials has been challenging. The WHO Solidarity Trial (Box 5.3) represents a novel and potentially capacity-building effort on clinical trials, which could be replicated (Keusch and Lurie, 2020[12]). The OECD Recommendation on the Governance of Clinical Trials (OECD, 2012[16]) is also relevant here, as the persistent lack of harmonisation between national regulations slows down the implementation of international clinical trials (OECD, 2020[17]).

These are some early observations concerning the successes and shortcomings of the international STI response to COVID-19. In time, as countries move from response to recovery, a fuller analysis and evaluation will be needed to draw lessons that should prove invaluable in informing STI collaboration for other "grand challenges", as discussed below.

Beyond COVID-19, international STI collaboration is needed to meet global challenges

Global public goods and global challenges

There is a sense of urgency to direct international STI co-operation activities towards "global challenges", broadly defined as persistent, complex and large-scale problems facing humanity. Such challenges require co-operative resources, because no single country can solve them alone (OECD, 2012[18]). A common feature that has characterised the collective response to COVID-19, through organisations and platforms like GAVI and CEPI, is the notion that certain global challenges are not simply challenges that require international co-operation, but that the very nature of the global challenge represents the under-provision of a GPG. A GPG is a good where "it is rational, from the perspective of a group of nations collectively, to produce for universal consumption, and for which it is irrational to exclude an individual nation from consuming, irrespective of whether that nation contributes to its financing" (Woodward and Smith, 2003[19]). Another definition is that GPGs are public goods that "cannot or will not be adequately addressed by individual countries acting alone and that are defined through a broad international consensus or a legitimate process of decision-making" (ITFGPG, 2006[20]; Miedzinski et al., 2020[21]). GPGs share certain properties with public goods, i.e. their non-excludability and non-rivalry. Non-excludability means that once provided, the public good is available to all to consume; non-rivalry means that consumption of the public good by one party does not reduce the amount available to the others.[13] A practical example of a GPG is greenhouse emissions control or a vaccine against a highly communicable disease that protects human populations in more than one country. Of course, vaccines are not *intrinsically* non-excludable because they are produced by private firms who can limit their universal accessibility through the price mechanism, but policy interventions in the form of government purchases and distribution through public health systems, for example, can make them less or non-excludable. Because of their limited economic resources, developing countries are especially exposed to global challenges and the under-provision of GPGs, and support from the international community is therefore essential.

The global challenges are heterogeneous. Some derive from public goods problems on a global scale, while others derive from global challenges on a national or bilateral/regional scale (e.g. pollution generated and concentrated in cross-border regions). While not all global challenges are public good problems, very little multilateral collaboration is around public-good production. On the contrary, policy-makers undertake collaboration where they can identify direct (and preferably quantifiable) benefits, in the form of increments to GDP, employment, or exports (Smith, 2017[22]). The challenge for countries is how to balance their national STI priorities and goals (e.g. competitiveness and research excellence) with the need for co-ordinated collective action at the international level to address global challenges, including GPG problems.

The international STI policy community needs to encourage a more collaborative mode of STI, in which shared goals and missions underpin individual and collective STI actions. However, mobilising international STI collaboration to address GPGs and global challenges faces several hurdles, the most notable being that collective action for the provision of the good suffers from an economic problem common to the provision of public goods; i.e. their under-provision by markets. Whereas a national public good can be provided by governments through taxation, there is no global government that can mobilise global tax revenues to provide such goods directly or through public procurement. Additional challenges include:

- different national research foci and limited alignment between national and global STI priorities;

- unwillingness of individual countries to pay the costs of action ("tragedy of the commons");
- lack of knowledge of different national capabilities, especially in developing countries;
- lack of trust and legal regimes, including appropriate IPR protection, especially in less-developed economies;
- low government and business capacity in some countries, including low number of researchers and lack of necessary research infrastructure to enable international co-operation;
- major problems to meet the necessary scale of investment and technological uncertainty requiring multiple search paths;
- governance arrangements to co-ordinate and manage multiple actors, necessary not only to advance the necessary STI, but also to deploy systems that deliver technological solutions; and
- implementation challenges including the lack of appropriate interface organisations such as technology extension centres or community organisations that can apply solutions to the local context.

Compounding the effects of these hurdles, international co-operation in research remains dominated by collaborations aiming first and foremost to advance the knowledge frontier or share costs on international research infrastructure, and to a much lesser extent to develop solutions to societal problems. Moreover, the direction of international research co-operation remains primarily driven by the "bottom-up" priorities of individual researchers and research performing organisations, even if a number of collaborations on climate change, global health, renewable energy or sustainable agriculture are initiated through "top-down" processes.

In this regard, the current paradigm for international co-operation in science can be seen to focus on: (i) raising the quality of national public research systems; (ii) sharing costs though scientific collaboration on basic research; (iii) promoting the international mobility of researchers for the (mutual) benefit of multiple partners; and (iv) internationalising public research. This paradigm has been successful in advancing knowledge among countries with the capacity to engage in research collaboration, i.e. mainly OECD countries; Brazil, Russia, India and China; and some emerging economies. With some notable exceptions in East Asia, it has been less successful in helping developing countries mobilise STI for their own development. Instead, these countries have relied on STI-related official development assistance (ODA) and multilateral development bank finance; imports of foreign technology and foreign direct investment; and, for middle-income countries, their own investments in education and science. Cost sharing under this paradigm is generally characterised by national control over funding: each country funds its share of international collaboration rather creating a "common pot" of funding (with the exception of the European Union's Framework and Horizon programmes). The response to COVID-19 by research funders has been similarly focused mainly at the national level, although it has been characterised also by co-ordination among national research funding agencies, for example, through GloPID-R (see Box 5.2).

Towards a new paradigm for international collaboration on STI

A focus on GPGs and global challenges requires a new paradigm for international STI co-operation that goes beyond cost-sharing and expanding fundamental knowledge through co-operation in basic research or mega-science projects. The immediacy and urgency of the current pandemic has brought home the need for a new paradigm of international co-operation in STI. This new paradigm will require new financing and governance mechanisms that bring together business and private-finance actors with multilateral and national development banks. These include tax and regulatory policies that will allow the international research system to incentivise and reward businesses and financial institutions to invest in solutions to GPGs. The new paradigm will also require specific institutional capabilities for multi-stakeholder partnerships to broker, orchestrate and fund global challenge-driven STI programmes. These new arrangements will need to manage growing tensions between the need for more global co-operation and

the increasingly inward-looking nature of national policies, which are more protective of STI as a source of national security and independence. These, and other challenges, are further discussed below.

International STI co-operation is fragmented

Research-funding agencies have a great deal of expertise in funding international collaborative projects that promote research excellence in specific disciplines and areas, but they are less well equipped to fund and organise collaboration to address grand challenges – especially those involving developing countries. Some very real practical challenges impede international collaboration, such as visas and work permits for researchers, or purely national grant schemes that do not allow financing international projects. Many research-oriented collaborations are uncoordinated on a global scale, many of the potential synergies from sharing costs or information are lost, and there exists a risk of duplicating research and innovation efforts. Data on international co-operative R&D projects around global challenges and the SDGs are also lacking, and yet such data would greatly enhance the ability of decision makers to monitor and evaluate these activities, and prioritise successful experiences. To reduce this fragmentation of international efforts, co-ordination of national public research agendas oriented toward global challenges is essential.

Institutional elements of the new paradigm aimed at building GPGs and addressing global challenges through international STI collaboration are already in place, but need to be consolidated and reinforced. Some of these institutional set-ups can build upon existing organisations, such as Canada's International Development Research Centre (IDRC), whose Technology and Innovation Program leverages science and advanced technologies, including digital innovations to build human capital to support inclusive growth in developing countries. New partnerships will also need to be created, such as the United Kingdom's Newton Fund, which was created in 2014 to fund collaborations on global challenges between academics and innovators in the United Kingdom and developing countries.

There already exist several examples of international collaboration focused on mobilising STI for global challenges. They range from mandate-based international organisations (e.g. the Consultative Group for International Agricultural Research, the International Energy Agency and Mission Innovation, and the Global Knowledge Centre for Antimicrobial Resistance R&D) to partnerships initiated by governments and philanthropies such as CEPI (see Box 5.2). One characteristic of these new partnerships is the involvement of a broader range of stakeholders, including companies, civil society groups and notably private philanthropic organisations.

International financing of GPGs: the case of blended finance in STI

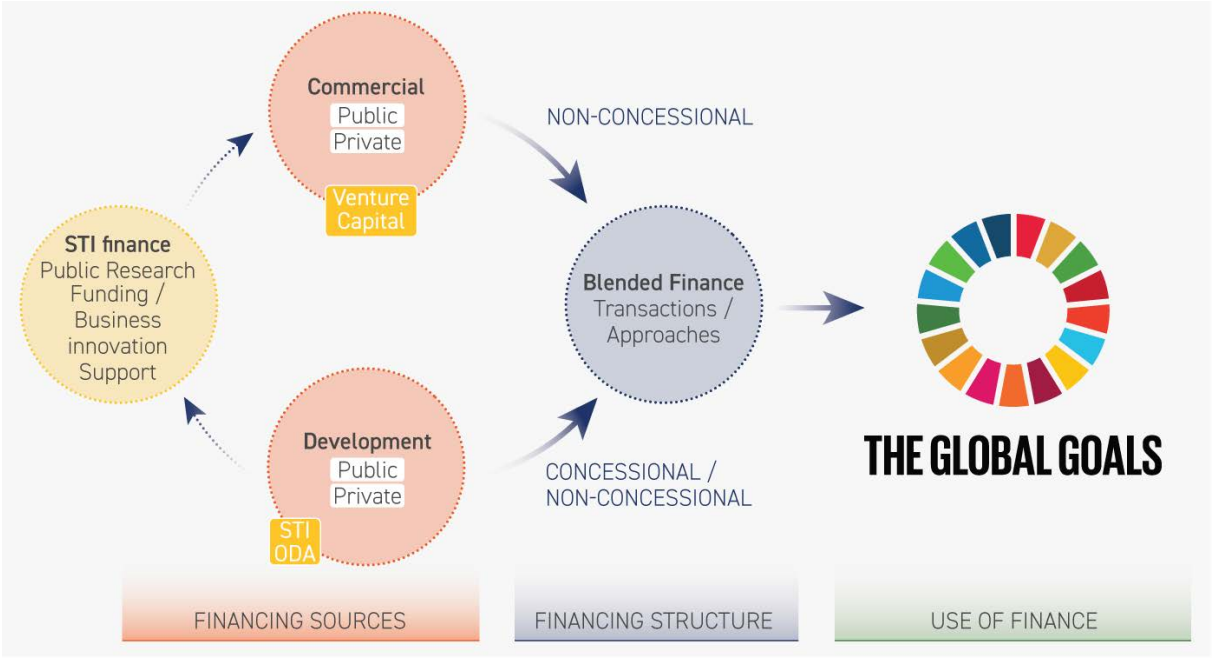
Addressing and delivering on global challenges, including GPGs, will require financial resources that exceed most countries' budgets for domestic public resources. Many estimates have been made of the investments needed to achieve the SDGs by 2030. One estimate points to an overall need for a USD 7 trillion annual investment up to 2030, representing 7-10% of global gross domestic product and 25-40% of annual global investment. By comparison, only USD 1.4 trillion are invested annually to meet the SDGs, leaving a vast investment gap. For developing countries alone, the investment gap has been estimated at around USD 2.5 trillion per year (Remøe and Cervantes, forthcoming[23]). Closing this gap will require mobilising financial resources from public coffers as well as the private sector, including investment banks, philanthropic sources and multilateral institutions.

Hence, many governments seek to combine public financial resources with private financing. "Blended finance", in the space of SDGs and Agenda 2030, has been defined as the strategic use of development finance for the mobilisation of additional finance towards the SDGs for and in developing countries. Blended finance has also been described as hybrid finance, or as a combination of concessional and commercial funding provided by public or philanthropic development partners, along with private partners. It can be structured around various formats combining grants, debt, equity or guarantees (insurance) from

public/philanthropic and private sources. The concept is also linked to the more general concept of social-impact investments.

A main idea of blended finance in STI is mobilising capital that would not otherwise be committed to development-related projects, including developing technology to create solutions that are relevant to the SDGs. Through blending financing, commercial capital may be moved to benefit society while also providing reasonable returns to investors. Thus, frameworks that remove disincentives and bottlenecks preventing private investors from targeting countries, sectors or technology areas for additional funding are needed (Figure 5.4).

Figure 5.4. Expanding the OECD framework for "blended finance" to STI finance



Source: Adapted from OECD Tri Hita Karana Forum on Blended Finance, http://www.thkforum.org (accessed 15 October 2020).

One example of such a framework is Deutsche Bank's Universal Green Energy Access Programme (UGEAP), which typically becomes involved when public actors provide a "first-loss" facility that buffers private investment. The UGEAP is, for example, active in African countries, where it contributes to universal electricity access. Another example is the European Investment Bank's recent Malaria Fund initiative to develop a cure.

Many schemes in development finance use these concepts to finance green technologies, agriculture technologies and health technologies when a private-only finance model does not work owing to market failures. However, fewer schemes seem to have been established (so far) to finance riskier technological innovation that requires a portfolio of projects. Combining private and public sources of finance is not new in STI, and risk-reduction schemes for private partners typically comprise grants or subsidies. Ultimately, blended finance implies an equal sharing of risk through joint positions regarding return on investments, and risk profiles and positions may be designed differentially according to project specificities (Remøe, 2020[24]).

Geopolitical developments and their impact on international STI co-operation

Although COVID-19 has led to greater calls for international co-operation, it has also led countries to reassess their reliance on global value chains – especially for essential goods – and consider national actions to strengthen their citizens' access to critical technologies, goods and services. This goal can appear in contrast with the GPG paradigm for international co-operation, where cross-border public R&D investments are a way to invest in a country's own national security and economic and technological development.

Indeed, efforts to mobilise national funding for projects related to global challenges can create tensions between the design of programmes to benefit national taxpayers and the realities of international economic and technological interdependence. Policy makers face strong (and understandable) pressures to ensure that foreign universities or firms are not taking a "free ride" on public R&D investment, with concerns expressed about subsidies, trade-related investment measures and IPR, to name only a few (see Chapter 4).

However, the response to these pressures often consists of increased restrictions on international scientific and technological co-operation, international researcher mobility and technology exports. Such measures may be counterproductive, especially if other countries can supply technology, as well as higher education and research opportunities to foreign students. Moreover, foreign firms can easily shift production to lower-cost countries to avoid trade tariffs, and can always acquire firms in foreign markets to diversify their production.

To balance the benefits and risks of international co-operation, governments will need to revamp the international rules for technology exchange and international STI co-operation, allowing allow them to rebuild trust, and find common and shared values. One such rule involves the notions of mutual benefit and reciprocity that have long guided international relations. Mutual benefit and reciprocity play out differently in research collaboration than they do in collaboration on innovation that is closer to the market. Concerns and even frictions between countries over "reciprocal access" to one another's innovation systems have been growing, including over access to soft and hard research infrastructure (e.g. skilled personnel, open-science and open-data systems), as well as to technology markets.

Scientific integrity and academic freedom in international scientific co-operation is another issue, which has normally been the domain of scientific academies and universities. Governments increasingly seek to promote a common understanding of these values as a way not only to ensure a level playing field for co-operation, but also to limit the risks to scientific co-operation, such as fraud or theft of intellectual property or research data.

Of course, public policies are just one element of the "national innovation systems" of OECD countries. The performance of these systems within the most advanced economies depends on the actions and decisions of business enterprises. For example, new policies that allow greater scrutiny of mergers and acquisitions to protect national interests have led to stronger controls on inward investment in "strategic sectors". Concerns over access by one country's firms to another country's technology base may be well-founded, but their resolution is likely to be slow because firms operate globally.[14]

The role of international organisations

International organisations have a role to play in helping link national investment strategies to global challenges. In the COVID-19 context, the WHO continues to lead the international response to the immediate health crisis (see Box 5.2), for example, through the ACT-Accelerator (see Box 5.3). As part of the OECD's strategic response to the COVID-19 pandemic,[15] the Committee for Scientific and Technological Policy (CSTP) has created a policy platform, the STIP COVID-19 Watch, to monitor and collect information on countries' responses to the COVID-19 crisis around a core set of issues, including

scientific advice arrangements, promotion of R&D collaboration, and the STI content of economic stimulus packages (OECD, 2020[25]).

The EU has similarly been active on the STI policy front through its ERAvsCorona Action Plan (European Commission, 2020[26]) launched in April 2020 that sets out key measures to co-ordinate, share and jointly increase support for research and innovation to address COVID-19, in line with the objectives and tools of the European Research Area. The United Nations has also mobilised its agencies to contribute to the UN Research Roadmap for the COVID-19 Recovery.[16] The Roadmap articulates five research priorities for each of the five pillars identified in the UN Framework for the Immediate Socio Economic Response to COVID-19. The UN Roadmap aims to guide global research efforts, minimise research gaps and duplication, and foster partnerships in order to accelerate progress toward the SDGs. The UN initiative on STI Roadmaps for the SDGs is an another example of a policy exercise aiming to help member states engage multiple stakeholders, including development aid agencies, economic ministries and STI ministries, to align investments and policies to direct and scale up support for the SDGs (Box 5.3).

Box 5.4. STI Roadmaps for the SDGs as a tool to support international STI co-operation on global challenges

As part of the Technology Facilitation Mechanism (TFM), the United Nations' Inter-agency Task Team (IATT) has been working towards developing STI Roadmaps for SDGs as a tool to strengthen international co-operation on global challenges. STI for SDGs Roadmaps can help align national STI policy agendas with the SDGs, and develop new instruments and partnerships for international STI co-operation on global challenges in both developing and developed countries. The evidence suggests that the most effective collaborations are aligned with the domestic policy agendas of key partners.

The STI for SDGs Roadmaps are based on the following pillars:

- Pillar 1 – Building up national STI capabilities to address the SDGs: focus on strengthening national STI capabilities, mostly in developing countries, to address challenges underpinning the SDGs; any well-functioning national innovation system needs to be connected internationally.
- Pillar 2 – Boosting international knowledge and technology flows for the SDGs: focus on expanding international flows of relevant knowledge and technology across countries, and supporting cross-country STI collaborations addressing the SDGs.
- Pillar 3 – Brokering international STI collaborations for the SDGs: focus on brokering international collective STI actions aiming to tackle global challenges, notably GPGs.

The work of the United Nations Interagency Task Team on Science, Technology and Innovation for the SDGs Roadmaps illustrates the potential benefits of policy roadmapping. In particular:

- Donor countries can improve policy coherence by streamlining challenge-oriented STI policies with ODA.
- Developing countries can co-ordinate and synergise STI-related efforts among ministries, international partners and key stakeholders.
- Countries, international organisations and key partners at the global level can engage in concerted analytical and facilitation efforts to share knowledge and experience, disseminate and apply good practices, and design new or improved mechanisms.

- Scientists need to be mobilised around the globe through international collaborations (e.g. the Intergovernmental Panel on Climate Change of the United Nations [IPCC]) focused on orchestrating and conducting collective actions to co-develop and deploy innovations at the adequate scale to achieve transformative impact.

Source: United Nations (2020[27]), *Guidebook for the Preparation of STI for SDGs Roadmaps*, https://sustainabledevelopment.un.org/content/documents/26937Guidebook_STI_for_SDG_Roadmaps_final_Edition.pdf.

Outlook for international STI collaboration

Despite the various restrictions brought about by the COVID-19 crisis, the immediate response of the international scientific community gives rise to optimism that international co-operation remains strong and will continue to advance. The response also generates hope that STI co-operation for grand challenges and GPGs can finally become a core objective of the scientific community, alongside advancing knowledge and the scientific frontiers that have characterised much STI collaboration in the 20th century. Such a shift will not be straightforward, and will require scientific institutions to adapt by placing more value on challenge-driven, transdisciplinary research than is currently the case (see Chapter 3).

The collective action to combat COVID-19 provides some useful lessons and new approaches for enhanced global STI co-operation. Governments need to take bolder initiatives to increase support to STI co-operation for both grand challenges and GPGs. R&D preparedness to manage numerous potential global crises besides human-disease pandemics should be a leading policy priority. 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 (in the form of CEPI and its partners) to develop agile technology platforms that can be activated as new pathogens emerge. Although these relatively new arrangements are performing well, they are underfunded and dependent on a handful of countries and philanthropic institutions for financing. Pending discussions among governments and other stakeholders, they could be scaled up and extended to other areas where R&D preparedness for crises is important, capitalising on the momentum from the response to COVID-19.

Many global grand challenges do not present themselves in the same way as a pandemic. Global challenges like climate change and biodiversity loss are “slow-burning” crises that can only be tackled through international STI collaboration. This chapter has argued for a new paradigm of international STI co-operation. It has shown that elements of such a paradigm are already in place, but need to be consolidated and reinforced. In particular, governments 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 and GPG problems. The rapid and unprecedented mobilisation of public and private R&D funding for COVAX has demonstrated that new innovative funding models can be deployed to address global challenges through international STI co-operation.

Effective and transparent multilateral institutions and programmes have a role to play in this new paradigm. Programmes such as the International Clinical Trials Registry Platform are helping countries share information and data on COVID-19 vaccine trials. Existing international organisations and research infrastructures (see Chapter 2) are being mobilised to analyse data on the coronavirus and provide solutions to local research teams in diverse areas, from diagnostics to medical equipment. In time, new institutions (or new mandates for existing institutions) will be needed. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services is an example of a fresh intergovernmental initiative to protect biodiversity.

Government responses to the COVID-19 pandemic highlight the importance of national politics, leadership and values in influencing international STI co-operation (Cohen, 2020[28]). Governments will need to balance national STI priorities and goals with the need for internationally co-ordinated action to address the grand challenges and GPG problems. Without such collective action, the capacities to deal with them – in the form of scientific knowledge, technology platforms and international co-ordinating institutions – will remain underdeveloped, leaving countries more exposed to global shocks.

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Notes

[1] Much of this growth has been enabled by the increased mobility of researchers and the growth of science in middle-income countries.

[2] https://www.gisaid.org/.

[3] https://www.covid19dataportal.org/.

[4] If taken together, the European Union is the second largest contributor to the scientific literature on COVID-19. It also has almost the same number of co-authored papers as the United States – 16 483 in the first 11 months of 2020, 77% of which were domestic co-authorships, compared to 16 964 in the United States, 84% of which were domestic.

[5] https://www.bmbf.de/de/karliczek-unsere-foerderung-ebnet-der-impfstoff-forschung-gegen-covid-19-den-weg-12729.html.

[6] The ACTIV website lists the following companies as participants: AbbVie, Amgen, AstraZeneca, Bristol Myers Squibb, Eisai, Eli Lilly and Company, Evotec, Gilead, GlaxoSmithKline, Johnson & Johnson, Merck & Co., Moderna, Novartis, Novavax, Pfizer, Rhythm Therapeutics, Roche-Genentech, Sanofi, Takeda and Vir Biotechnology.

[7] The R&D Blueprint was subsequently updated in 2017. See https://www.who.int/teams/blueprint/about.

[8] The European Union is a major funder of COVAX.

[9] After China joined COVAX in October 2020, the only large countries remaining outside of the facility at the end of 2020 are the United States and Russian Federation.

[10] In an advance market commitment (AMC), buyers commit in advance to purchasing a specified volume of a health technology still in development at a guaranteed price and if it meets specific criteria. Thus, AMCs not only incentivise R&D, but also the production and delivery of the final product, because funds are only disbursed upon its purchase. Once the guaranteed volume is purchased, the manufacturer is contractually obliged to supply further volumes at a lower price. A two-stage pricing system is therefore in place: one relatively high price, guaranteed up to a fixed volume purchased, which provides a risk-adjusted return to the R&D investment made by the producer; and a second, lower price, set at a level closer to the cost of production (the "base price"). Criteria specified in the commitment include technical requirements such as the disease to be prevented or treated, the target population, minimum efficacy, dosage, route of administration, storage, and quality and safety requirements. AMCs can also specify conditions for procurement, licensing of IPR and affordability or access (OECD, 2020[15]).

[11] The funding will be used to support the procurement of safe and effective COVID-19 vaccines for 92 AMC-eligible countries, which include all economies with a gross national income per capita under USD 4 000.

[12] According to the CEPI website, "Wave 2 vaccines are candidates in early stages of development that offer scientific, technical or manufacturing differentiation compared to candidates currently in advanced development. They will be selected based on characteristics that could make them particularly suitable for use in specific target populations – such as older or immune-compromised individuals, or pregnant women – and also in low-resource settings where logistical challenges can make the use of certain vaccine approaches more challenging. The selection criteria include potential to protect from COVID-19 after a single vaccine dose, temperature stability, manufacturing scalability, improved or differentiated immune response, and the use of different antigens. Vaccine candidates in the Wave 2 Portfolio will be subject to global access commitments which will require vaccine output funded by CEPI's investment to be made available for procurement and allocation through COVAX." (CEPI, 2020[30]).

[13] Elinor Ostrom made a vital contribution to thinking on public goods by focusing on subtractability of the resource units, which allowed her to distinguish between public goods and common-pool resources (CPRs). CPRs are "a natural or man-made resource system that is sufficiently large as to make it costly (but not impossible) to exclude potential beneficiaries from obtaining benefits from its use" (Ostrom, 2015[29]). Whereas crowding effects and overuse problems are irrelevant for public goods (e.g. weather forecasts), they are chronic for CPRs, where overconsumption can lead to temporary or permanent negative impacts on man-made structures or biological resources.

[14] Similarly, global firms can tap into R&D tax credits in one country but choose to operate production in other countries for competitive reasons, depriving the country offering the tax subsidy of broader economic returns.

[15] https://www.oecd.org/coronavirus/en/.

[16] https://www.un.org/en/pdfs/UNCOVID19ResearchRoadmap.pdf.