UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT

UNCTAD

# TECHNOLOGY AND INNOVATION REPORT 2018

## Harnessing Frontier Technologies for Sustainable Development

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## Harnessing Frontier Technologies for Sustainable Development

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# FOREWORD

We live at a time of technological change that is unprecedented in its pace, scope and depth of impact. Harnessing that progress is the surest path for the international community to deliver on the 2030 agenda for people, peace and prosperity. Frontier technologies hold the promise to revive productivity and make plentiful resources available to end poverty for good, enable more sustainable patterns of growth and mitigate or even reverse decades of environmental degradation. But technological change and innovation need to be directed towards inclusive and sustainable outcomes through a purposeful effort by governments, in collaboration with civil society, business and academia. If policy-makers are not proactive technological disruption can entrench inequality, further marginalize the poorest, and fuel reactionary movements against open societies and economies.

The *Technology and Innovation Report 2018: Harnessing Frontier Technologies for Sustainable Development* notes that change is becoming exponential thanks to the power of digital platforms and innovative combinations of different technologies that become possible every day. This opens exciting possibilities for the democratization of frontier technologies to materialize in development solutions. The Report proposes strategies and actions, some of them based on existing experiences in STI policy for development, and some more innovative ones to make technology an effective means of implementation of our common development agenda – nationally and globally.

The Report also suggests that countries develop policies to help people navigate the transition period that lies ahead. This may require that stakeholders adapt the social contract to the new world that frontier technologies are forming. Education will become an even more indispensable lever for development and social justice. Since digital technologies as enablers and multipliers of other frontier technologies we should ensure that all – and specially women and girls – are given a real chance to build digital capabilities. Lifelong learning will need to be supported. For those who may struggle to keep up with the transformation, countries will have to be innovative in providing effective social protection mechanisms.

Most crucially, there is an urgent need for a sustained effort by the international community to ensure that the multiple gaps in technological capabilities that separate developed and developing countries are closed. Investment in hard and soft infrastructure and human capital, complemented by a scaled up, coherent and accelerated effort to enhance innovation systems for sustainable development are necessary to spread the economic, social and environmental benefits of frontier technologies.

By providing a platform for policy dialogue and experience-sharing, and through our capacity-building programmes, UNCTAD and the UN Commission for Science and Technology for Development, which we service, have an international policy role to fulfil in the development of the global response to those challenges. Our intention is that the Technology and Innovation Report 2018 will help launch a dialogue about how to harness technology for the achievement of the SDGs and in larger and more profound sense, the shared future of the people of the world.

Mukhisa Kituyi

Secretary-General of UNCTAD

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# ABBREVIATIONS

| | |
|---|---|
| **ASEAN** | Association of Southeast Asian Nations |
| **BDA** | Big Data Analysis Initiative (Malaysia) |
| **CERN** | European Organization for Nuclear Research |
| **CRISPR** | clustered regularly interspaced short palindromic repeats |
| **FDI** | foreign direct investment |
| **GDP** | gross domestic product |
| **GIF** | Global Innovation Fund |
| **GPS** | global positioning system |
| **HAPS** | high-altitude platform station |
| **ICT** | information and communication technology |
| **IDC** | International Data Corporation |
| **ILO** | International Labour Organization |
| **IoT** | Internet of Things |
| **IP** | intellectual property |
| **IPR** | intellectual property right |
| **kWh** | kilowatt-hour |
| **LDC** | least developed country |
| **M&E** | monitoring and evaluation |
| **MOOC** | massive open online course |
| **OECD** | Organization for Economic Cooperation and Development |
| **PED** | platform for economic discovery |
| **PV** | photovoltaic |
| **R&D** | research and development |
| **S3** | smart specialization strategy |
| **SME** | small and medium-sized enterprise |
| **STEM** | science, technology, engineering and mathematics |
| **STI** | science, technology and innovation |
| **TRIPS** | trade-related intellectual property rights |
| **TRIPS Agreement** | Agreement on Trade-Related Intellectual Property Rights (WTO) |
| **TVET** | technical and vocational education and training |
| **UBI** | universal basic income |
| **UIS** | UNESCO Institute for Statistics |
| **UNDP** | United Nations Development Programme |
| **UNIDO** | United Nations Industrial Development Organization |
| **UNESCO** | United Nations Educational, Scientific and Cultural Organization |
| **WEF** | World Economic Forum |
| **WFP** | United Nations World Food Programme |
| **WTO** | World Trade Organization |

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# OVERVIEW

The 2030 Agenda for Sustainable Development sets ambitious global goals, demanding unprecedented actions and efforts across multiple interconnected social, economic and environmental issues. Science, technology and innovation (STI) must play a central role in the achievement of these goals. The process of creative destruction initiated by technological progress can help to transform economies and improve living standards, by increasing productivity, reducing production costs and prices, and helping to raise real wages.

Harnessing frontier technologies – combined with action to address persistent gaps among developed and developing countries in access and use of existing technologies, and to develop innovations (including non-technological and new forms of social innovation) – could be transformative in achieving the Sustainable Development Goals and producing more prosperous, sustainable, healthy and inclusive societies. They offer the prospect of solutions and opportunities for sustainable development that are better, cheaper, faster, scalable and easy to use. The extent of the developmental impact of technological advances has already been seen in the transformative effects of information and communication technologies (ICTs) in many low-income economies, while the potential to increase the environmental sustainability of development is evident in recent advances in renewable energy. However, new technologies threaten to outpace the ability of societies and policymakers to adapt to the changes they create, giving rise to widespread anxiety and ambivalence or hostility to some technological advances.

## I. FEATURES AND POTENTIAL OF FRONTIER TECHNOLOGIES

The dramatically accelerating pace of development and adoption of new technologies in recent decades is likely to continue, driven by (a) the cumulative nature of technological change; (b) the exponential nature of technologies such as microchips, which have doubled in power every two years for half a century; (c) the convergence of technologies into new combinations; (d) dramatic reductions in costs; (e) the emergence of digital "platforms of platforms" – most notably the Internet; and (f) declining entry costs.

Several frontier technologies show the greatest potential to enable the achievement of the Sustainable Development Goals. **Big data** analysis can help to manage or resolve critical global issues, create new scientific breakthroughs, advance human health and improve decision-making, by providing real-time streams of information. **The Internet of Things** allows the condition and actions of connected objects and machines to be monitored and managed, and allows more effective monitoring of the natural world, animals and people. These two technologies have important applications in health care, agriculture, energy and water management and quality, as well as in monitoring development indicators to assess progress towards the Sustainable Development Goals. Governments should consider developing strategies to harness these technologies towards their development goals.

**Artificial intelligence** now includes capabilities in image recognition, problem solving and logical reasoning that sometimes exceed those of humans. Artificial intelligence, particularly in combination with robotics, also has the potential to transform production processes and business, especially in manufacturing. So too does **3D printing**, which can allow faster and cheaper low-volume production of complex products and components, and rapid iterative prototyping of new manufactured products. In addition to offering some potential carbon savings by reducing the need to transport components, 3D printing can offer benefits in health care, construction and education.

Extraordinary advances in **biotechnology** allow very specific gene editing for human medicine, making personalized treatments possible for certain conditions in combination with artificial intelligence and big data, as well as for genetic modification of plants and animals. **Nanotechnology** – the manufacture and use of materials at an infinitesimal scale – has important applications in water supply (water purification), energy (battery storage), agriculture (precise management of the release of agrochemicals), ICT (reducing the size of electronic components) and medicine (delivery mechanisms for medication). **Renewable energy** technologies allow the provision of electricity in remote and isolated rural areas inaccessible to centralized grid systems, while **drones** could revolutionize the delivery of supplies, enable precision agriculture and replace humans in dangerous tasks. Small-scale customized **satellites** will soon be affordable for more developing countries, businesses and universities, allowing monitoring of crops and environmental damage.

## II. ECONOMIC AND SOCIETAL CHALLENGES

The relationship between technology and employment has long been controversial. Like earlier technological advances, frontier technologies can be expected to eliminate some jobs, while creating others. While the net effect on employment remains ambiguous, there are already signs of a polarization of employment between low- and high-skilled non-routine jobs, as jobs at medium skill levels have declined. There are also signs that the net impacts may be most unfavourable for women.

For most developing countries, the impact of frontier technologies on employment is likely to depend less on their technological feasibility than on their economic feasibility. Fears about short-term adverse effects of digitalization and automation on employment may be exaggerated, particularly if labour and education policies promote complementarity between skills available in the workforce and new technologies. Since the impact of technology depends on the structure of each country's economy, the impact at the national level cannot be assumed to be necessarily negative, but rather requires a balanced analysis of the net effects of technological and market forces. Thus, the future lies in workers creating economic value with machines rather than against them.

Effects on productivity are also ambiguous, as emerging technologies will by no means be universally adopted. Expert opinion is divided between those who see a secular decline in productivity, and those who see a divergence between "frontier" firms that adopt new technologies and reach historically high productivity, and other firms that lag behind. However, the interpretation of current trends is complicated by issues pertaining to the appropriateness of existing indicators to measure productivity in the new technological era.

Emerging digital technologies such as big data and the Internet of Things also give rise to important issues of citizen's rights, privacy, data ownership and online security. This highlights the need for effective institutional frameworks and regulatory regimes for data collection, use and access, to safeguard privacy and security, balancing individual and collective rights and allowing private sector innovation. Similar considerations apply to concerns about technological convergence driving simultaneous convergence in platforms, commercial interest and investments that can result in concentration of market power.

While the implications of frontier technologies remain uncertain, it is clear that they hold the potential for profound positive implications for almost every aspect of sustainable development. They also involve a potential risk of exacerbating existing economic, social and technological divides, as countries with strong existing capabilities harness new technologies for development, leaving others ever further behind.

Applying technology to the challenges of achieving the Sustainable Development Goals requires building local capacities and developing policies and an enabling environment – as well as unprecedented resource mobilization, partnerships and multilateral global collaboration – to (a) fund research and development (R&D) that is relevant to the Sustainable Development Goals; (b) build networks; (c) strengthen the global science–policy interface; (d) transfer technologies; and (e) support the development of capabilities in developing countries. Current national and international efforts are seriously inadequate for this task. Wide and persistent gaps in STI capacities, multiple digital divides and insufficient investments in STI limit the discovery, development, dissemination and absorption of technologies that could accelerate the achievement of the SDGs. Alongside resource mobilization, a scaled up and accelerated application of policies is needed to enhance innovation systems for sustainable development and spread the economic, social and environmental benefits of frontier technologies.

## III. THE DIVIDE IN TECHNOLOGICAL CAPABILITIES

Capabilities are critical to countries' ability to exploit the opportunities offered by new and emerging technologies – and there is a wide gap in capabilities between developed and developing countries.

**R&D expenditures** in developing countries (except for the Republic of Korea, Singapore and China), remain much smaller both in absolute terms and relative to gross domestic product, than the world average. In large part, this reflects low business R&D expenditures: with the same three exceptions, business accounts for 32–38 per cent of R&D in developing countries, around half the world average of 68 per cent.

Despite significant growth since 2000 in the numbers of **researchers** in most developing regions, they are very unevenly distributed around the world, relative to population, with disproportionate numbers in Europe and North America. In 2014, there were 1,098 researchers per million people globally, but only 87.9 per million in sub-Saharan Africa, and 63.4 per million in least developed countries (LDCs).

The geographical distribution of **science, technology, engineering and mathematics (STEM) graduates** is also very unequal, with two thirds of them being in Asia – mainly in India (29.2 per cent) and China (26 per cent) – only 5.2 per cent in Latin America and less than 1 per cent in Africa. This partly reflects a share of STEM in tertiary education well above the global average in Asia, especially China.

## IV. THE CRITICAL ROLE OF SKILLS TO COMPLEMENT FRONTIER TECHNOLOGIES

Research capacity, however, is only one aspect of the capabilities needed for the exploitation of new technologies. Also important are generic, core and fundamental skills that are complementary to new technologies – such as literacy, numeracy and basic academic skills – together with basic financial and entrepreneurial skills and, increasingly, basic digital and even coding skills. Internet access is also critical. Besides advanced cognitive skills, such as STEM, inherently human skills and aptitudes are also gaining increasing importance, as they are difficult for robots and machines to emulate. These include various behavioural, interpersonal and socio-emotional skills, creativity, intuition, imagination, curiosity, risk-taking, open-mindedness, logical thinking, problem-solving, decision-making, empathy and emotional intelligence, communication, persuasion and negotiation skills, networking and teamwork, and the capacity to adapt and learn new abilities.

Matching the supply of skills to rapidly evolving market needs is critical. This requires agility in education policies, and may mean transforming education and training systems, as there are signs that education institutions are not keeping pace with technological advances, giving rise to skills shortages, especially in digital technologies. While big data can play an important role, this also requires a holistic approach, with collaboration among policymakers, education and training systems, and employers.

Curricula need to be adapted to emphasize the skills that are becoming more significant. Teachers' methods also need to change to reorient education towards more practical, applied and experimental learning approaches, and the development of skills, competencies and capacities for continuous learning. Digital and online methods have an increasing role to play.

## V. TECHNOLOGY AND DIGITAL GENDER DIVIDES

A key issue is the gender divide in STEM, information technology and computing. Globally, only 28 per cent of researchers were women in 2013, with still wider gender gaps in South and West Asia, and in East Asia and the Pacific. Despite increases in sub-Saharan Africa, the Arab world and parts of Asia, the proportion of women researchers in engineering and technology in most developing countries is 10–40 per cent. Women are also a steadily declining minority among graduates in computer science, and are underrepresented among STI decision makers.

Women are also seriously underrepresented in the digital sector. There is a major gender divide in mobile phone ownership, especially in South Asia, and in Internet use, especially in LDCs and sub-Saharan Africa, where the gap has widened since 2013. The gender gap in access to the Internet is now an intolerable 16.1 per cent in developing countries and 11.3 for the world a s a whole.

Access to energy is a major constraint to increasing ICT access for men and women alike, especially in rural areas. Decentralized energy systems, based on mini- or microgrids using renewable energy technologies, offer considerable potential to address this issue, particularly in LDCs, if technological, economic, financial and governance issues can be overcome.

The significant and persistent divide between countries in STI capabilities can both perpetuate existing inequalities and create new inequalities, particularly affecting LDCs. Addressing this divide will require strengthening national strategies in developing countries, as well as complementary international support measures, to enable them to harness new and emerging technologies effectively for sustainable development.

## VI. HARNESSING FRONTIER TECHNOLOGIES REQUIRES ATTENTION TO THE BASICS OF STI POLICY

The overarching challenge for developing countries to reap the benefits from frontier technologies, as much as from more established ones, is to learn, adopt and disseminate knowledge and technologies to promote sustainable development. Success is dependent on the effectiveness of relevant innovation systems, which are weaker and more prone to systemic failures and structural deficiencies in developing countries. While centred on firms, innovation systems that also encompass research and education systems, government, civil society and consumers – and their effectiveness – rest on the capabilities of these various actors, the connections among them, and the enabling environment for innovation that they create.

In developing countries with nascent innovation systems, most actors need first to develop a basic capacity to learn how to adopt, assimilate and diffuse existing knowledge and technologies. This is an essential requirement for technology transfer, which is a complement to, not a substitute for, efforts to build endogenous innovation potential.

Connections among actors are equally essential, to facilitate learning, technology adoption and the development of new technologies. This requires networking and collaboration capabilities among all actors, even where there are innovation intermediaries or knowledge and technology brokers. Where the local knowledge base is underdeveloped and access to market intelligence limited, developing links with foreign firms, funders and research centres is a key step. While innovation collaboration can occur spontaneously, it often requires active facilitation by government or non-government actors, especially in areas related to social and environmental challenges.

An effective innovation system requires attention to the five key elements of innovation systems as an enabling environment:

(a) The regulatory and policy framework, which should provide a stable and predictable environment to facilitate long-term planning by firms and other innovation actors;

(b) The institutional setting and governance, which should be oriented towards incentivizing actors to invest in productive rather than rent-seeking activities;

(c) The entrepreneurial ecosystem, which should provide flexible access to finance, through appropriate and readily accessible financial instruments, together with organizational capabilities and managerial competences;

(d) Human capital, including both the technical and managerial skills involved in innovation activities, through a strong technical and vocational education system; and

(e) Development of technical and R&D infrastructure, including ensuring affordable access to ICT and overcoming geographical, gender, generational and income digital divides.

Access to affordable financing is a major constraint to R&D, technology and innovation, especially in LDCs. Traditional financial systems have proved poorly suited to meeting the needs of innovation, particularly in the earliest stages of technology development and innovation, due to a combination of uncertainty and market failures related to asymmetric information, principal–agent problems and the limited ability of private agents to appropriate knowledge.

This has led to most Governments becoming involved, directly or indirectly, in financing R&D, technology and innovation. Tax incentives are widely used, and have generally been found to be effective, but with uncertain fiscal costs. However, successful innovation systems require a combination of public finance and development bank funding, often including grants, with private capital, market-based solutions and philanthropic financing. An important objective of STI policy is to promote the development of financing instruments appropriate to each stage of the innovation process. Useful mechanisms include matching grants for seed funding, and lending or loan guarantees by development banks in priority areas.

Intellectual property protection, particularly through patents, is an important issue for innovation. Such protection has strengthened in recent years, partly as a result of "TRIPS (trade-related intellectual property rights)-plus" provisions in free trade agreements and bilateral investment agreements. While intended to promote innovation, patent protection does not necessarily lead to better development outcomes, as most patents have been taken by foreign rather than domestic firms, limiting the scope for local innovation.

Creation of low-cost research activities is generally a higher priority, and may be encouraged by a "petty patent" system, granting less stringent protection to relatively unsophisticated innovations.

While strengthening intellectual property protection globally was intended to encourage technology transfer, particularly to LDCs, it can do so only as part of the wider indigenous innovation system, in conjunction with industrial and other policies, and with adequate local capabilities.

There are important areas of tension between intellectual property protection and the realization of the potential of frontier technologies in areas such as agriculture, health and energy, suggesting that an exclusive focus on strengthening intellectual property protection may be inappropriate. The principle of policy space for flexibility and inclusiveness is fundamental, to allow intellectual property regimes to be geared to each country's needs and capacities, through an appropriate balance between the granting of exclusive rights and the promotion of follow-on innovation by competitors.

## VII. POLICY COHERENCE IS CRITICAL

To be fully effective, STI policies need to be internally consistent and fully aligned with national development plans. The former can be promoted through the design and deployment of strategies and policy instruments at the most appropriate level, while the latter requires a "whole-of-government" perspective, facilitating cooperation across ministries and other public bodies in different fields of policy. Coherence is needed across policy areas such as industrial policies and those on STI, foreign direct investment (FDI), trade, education and competition, along with macroeconomic policies, including monetary policies.

Key steps towards building synergies between STI policy and overall development strategies include:

(a) Conducting a critical review of the innovation system and STI policy;

(b) Building a shared vision and choosing strategic priority areas for STI policy;

(c) Facilitating strategic partnerships;

(d) Designing a long-term STI strategy and policy road map; and

(e) Establishing monitoring and evaluation systems and nourishing policy learning.

Establishing advanced capabilities in policy design and implementation is a priority area for capacity-building.

## VIII. REDIRECTING INNOVATION TOWARDS INCLUSIVENESS AND SUSTAINABILITY

Addressing the challenges of inclusiveness and sustainability in the context of the 2030 Agenda for Sustainable Development requires (a) broadening the strategic focus of STI policy to integrate societal challenges at its core; (b) internalizing the direct and indirect contributions of innovations to economic, social and environmental aspects of sustainable development; and (c) fostering transformative innovations with the potential to supplant unsustainable practices and systems.

Concerns about the employment implications of frontier technologies have fuelled a growing debate about the need to adapt the social contract to a new context of rapid change in technology, but also in key parameters of the social, cultural and political environment. Two themes have emerged consistently in this debate: (a) **lifelong learning**, through skills updating and skills upgrading, can help to match the supply of skills to match demand, while allowing workers to adapt to a rapidly changing labour market; and (b) **universal basic income (UBI),** periodic cash payments made unconditionally to all members of society, has been proposed as a means to provide financial security both to those unable to adapt successfully to changing skills needs and to potential innovators. A number of (mostly local) experiments are underway, and the preliminary results are encouraging; but the considerable fiscal cost remains an obstacle.

Beyond these foundations of STI policy, several new concepts and policy approaches could further strengthen the contribution of technological change to the 2030 Agenda for Sustainable Development.

## IX. LEAPFROGGING: LOOK BEFORE YOU LEAP?

New and emerging technologies open opportunities for **leapfrogging** – bypassing intermediate stages of technology through which countries have historically passed during the development process. For most developing countries, however, limited capabilities mean that such opportunities arise primarily in the form of adoption of existing technologies – exemplified by the transformative effects of mobile telephony in

African countries – rather than the development of new technologies. While the case of the mobile telecom sector seems difficult to replicate, there is potential for leapfrogging in the energy sector through the development of decentralized renewable energy systems. This may provide a cost-effective means of accelerating sustainable development. Innovation policies can support such a process, if backed by finance, investment and technology transfer, but important technological, economic, financial and governance obstacles need to be overcome, particularly in LDCs.

## X. NEW APPROACHES TO INNOVATION

At the other end of the spectrum, **new concepts of innovation** are emerging that focus on inclusiveness, including pro-poor, inclusive, frugal, grass-roots and social innovation. Policies to support such approaches can help extend the benefits of innovation to previously excluded groups, promote informal innovation by marginalized groups, include local communities in the innovation processes, and promote innovations in social relationships, practices and structures to address social needs and improve well-being.

**Smart specialization** is an explicitly experimental variation of traditional vertical industrial policies at the regional level, based on systematizing and responding to the information generated by positive and negative policy results through a process of entrepreneurial discovery. Smart specialization involves the development of a set of transformative activities – collections of innovation capacities and actions oriented towards a particular structural change – aimed at focusing R&D, partnerships and the supply of public goods on particular opportunities, while facilitating collective actions among innovation actors. A key feature is the selection of priorities at the level of the transformative activities, rather than the sector or firm level, through transparent, decentralized and evidence-based interaction between the public and private sectors.

**Platforms for economic discovery** (PEDs) are based on the fundamentally economic, rather than technological, nature of innovation – the process of translating technological inputs into products, processes and services, and discovering whether it will be adopted, at what price, and through what kind of business model. This is insufficiently recognized, skewing policy and international support for innovation towards scientific and technological aspects. This report proposes an international cooperation effort to support the establishment of local and regional PEDs, focusing on smart specialization priorities, to provide entrepreneurs with the capacities, capabilities and services needed for innovation, to ensure a sufficient rate of return to economic discovery. Such an effort would provide a practical avenue for development partners to refocus and strengthen international cooperation for innovation.

**Incubators, accelerators and technology parks** can play a useful role as complements to smart specialization and PEDs. Their success depends on actively fostering the emergence of competitive start-ups and facilitating links between companies inside and outside of incubators.

## XI. SHAPING RESEARCH COLLABORATION TO ADDRESS THE SUSTAINABLE DEVELOPMENT GOALS

**Global collaboration in scientific research** has grown considerably over recent decades, opening new opportunities for the combination of the most advanced scientific capabilities, with detailed local knowledge in key areas of sustainable development. The capacities of many developing countries to participate in such collaboration have increased considerably. To direct such networks firmly towards achievement of the Sustainable Development Goals, Governments need to move beyond funding and managing R&D to influencing networks, which requires an understanding of their formation, organization, norms, dynamics, motivations and internal control mechanisms. Key interventions include (a) funding; (b) convening international events on particular aspects of the Sustainable Development Goals; (c) supplementing research grants with targeted support for travel and communications; (d) establishing prizes and awards; (e) establishing national platforms for collaborators on issues related to the Sustainable Development Goals; and (f) framing local problems in such a way as to attract international research attention. Development impact can be enhanced by mapping existing scientific knowledge and current research against local needs, to target research and avoid redundancy, and by the use of gap analysis to develop sufficient absorptive capacity to retain knowledge locally.

## XII. CHANGES IN THE FUNDING OF INNOVATION

Changes in financing also offer new opportunities for funding innovation. Policies can usefully support the emergence of **venture capital financing,** where the basic conditions exist (notably significant high-tech activity and scope for the creation of a critical mass of start-ups), and the development of active **angel investment** networks, including through support to upgrading of entrepreneurs. While the absence of active stock exchanges is an obstacle to developing venture capital, this can be averted by access to initial public offerings on foreign stock markets or regional exchanges, or by establishing secondary exchanges for small and medium-sized enterprise (SME) listings (thus making the investment in venture capital more liquid and hence more attractive), which can also create additional channels for risk financing.

**Impact investment** also merits further investigation as a potential avenue for funding STI for the Sustainable Development Goals, given its orientation towards social and environmental objectives, although it is currently focused mainly on developed countries and on mature private companies. **Crowdfunding**, too, offers potential, but (a) as with impact investment, currently exists mainly in developed countries; (b) is focused mainly on social and artistic causes and real estate activities; (c) largely takes the form of donations, rewards and preselling; and (d) is relatively small in scale. Before promoting crowdfunding, developing country Governments should consider the risks involved and establish appropriate regulatory positions, particularly for equity crowdfunding.

**Innovation and technology funds** financed by the public sector, international donors, development banks or the private sector have become an important instrument for innovation funding in developing countries. They have the advantage of being relatively fast to introduce, flexible in design and operation, and able to target particular industries, activities or technologies and support strategic goals, making them complementary to smart specialization and PEDs. However, their success relies in part on the strength of the innovation system as well as on their design.

All in all, new approaches offer some potential to build on the broader foundations of STI policy to promote innovation oriented towards sustainable development. But realizing the almost unlimited potential of technology and innovation to contribute to the 2030 Agenda for Sustainable Development will require action at the national and global levels to match the extraordinary ambition of the Sustainable Development Goals themselves.

# CHAPTER I

# FRONTIER TECHNOLOGIES AND SUSTAINABLE DEVELOPMENT

# A. INTRODUCTION

With the vision of "leaving no one behind", the 2030 Agenda for Sustainable Development demands unprecedented actions and efforts. Unlike the Millennium Development Goals, the Sustainable Development Goals are universal and comprehensive goals that give equal importance to the economic, social and environmental pillars of sustainable development. Islands of prosperity surrounded by poverty, injustice, climate change and environmental degradation are viewed as neither sustainable nor acceptable.

UNCTAD's research indicates that developing countries face an annual gap of $2.5 trillion in public and private investment relative to the needs of the Sustainable Development Goals (UNCTAD, 2014b), including $342 billion per year for low-income countries and around $900 billion per year for lower middle-income countries (UNCTAD, 2016d). Bridging such a gap is a formidable task, especially in least developed countries (LDCs).

The Sustainable Development Goals go beyond the Millennium Development Goals' objective of halving extreme poverty, to require its complete eradication everywhere by 2030. This is a particularly ambitious goal in LDCs – "the battleground on which the 2030 Agenda will be won or lost" (UNCTAD, 2015b) – where it means reducing poverty from 46 per cent to zero in 15 years, requiring a much greater economic miracle than that achieved by China since 1978 (UNCTAD, 2015c). The Sustainable Development Goals also envisage, inter alia, universal access to water, sanitation and affordable and reliable energy; combatting child mortality; reducing inequality within and among countries; making cities and human settlements inclusive, resilient and sustainable; and generating more productive jobs. It is clear that business as usual will fall far short of delivering these ambitious goals.

Science, technology and innovation (STI) played a pivotal role in the progress towards the Millennium Development Goals; and the new and more ambitious 2030 Agenda will require still greater engagement by the global STI community. This is recognized explicitly in Sustainable Development Goal 17, which identifies technology as an important means of implementation of the Sustainable Development Goals, while Goal 9 specifies innovation as a mechanism for transforming economies, tackling vulnerability, building resilience and achieving inclusive prosperity. The role of STI is also formally recognized in other global development policy agreements.[1]

The task of achieving the Sustainable Development Goals is complicated by the multiple interconnected social, economic and environmental issues involved, including poverty, food security, nutrition, health, water and sanitation, energy access and access to ICTs. The depth and complexity of these interconnections requires new forms of development in STI.

The 2030 Development Agenda is being pursued in a context of profound transformation, driven by rapidly evolving and often converging technologies that are expected to change radically the operation of production systems, the roles of different players along value chains and even the definitions of sectors and industries themselves. Beyond their potential for economic development, frontier technologies may have far-reaching implications for the ability of societies to respond to many pressing social and environmental needs. They also give rise to concerns, increasingly present in the global public debate, about their consequences for equality, employment and the industrialization prospects of developing countries. For these reasons, this report focuses on the opportunities and challenges of harnessing frontier technologies for sustainable development.

Far from removing the need to address the persistent gap between developed and developing countries in their ability to benefit from technology, frontier technologies reinforce the urgency of sustained efforts by the international community to ensure that no one is left behind in the race to the new world that they are forming. This report therefore outlines strategies and actions to increase the effectiveness of frontier and established technologies as means of implementation of the 2030 Agenda nationally and globally, combining existing experiences in STI policy for development with more innovative approaches. It should, however, be emphasized that the focus of this report on the role of technological innovation in development does not imply a disregard for the power of non-technological

1 The Addis Ababa Action Agenda of the 2015 Third International Conference on Financing for Development, for example, singles out technology for emphasis. The first outcome of this conference to be implemented was the establishment of the United Nations Inter-agency Task Team on STI for the Sustainable Development Goals and the launching of the Technology Facilitation Mechanism. The recently adopted Paris Agreement on Climate Change also underlines the centrality of STI in the mitigation and adaptation efforts.

(organizational, institutional and social) innovation as an engine of social and economic transformation. UNCTAD is currently exploring how to incorporate these dimensions of innovation more effectively in its policy work and technical cooperation programmes, and they will be the subject of analysis in future publications

## B. FRONTIER TECHNOLOGIES: UNPRECEDENTED POSSIBILITIES, INTRACTABLE CHALLENGES

The social, economic and environmental challenges of the twenty-first century and the ambitious agenda of the Sustainable Development Goals coexist with frontier technologies that can and should play a major role in finding and applying the necessary global solutions. Such technologies provide fundamentally new and often underappreciated possibilities for economic development, environmental protection, education and governance, offering the potential for a world of far greater prosperity, while enhancing environmental sustainability and mitigating climate change. Many of these technologies also offer the prospect of solutions and opportunities that are:

(a) **Better**, in that they solve problems more effectively, provide new capabilities and opportunities, and allow much more efficient use of natural and human resources;

(b) **Cheaper**, in that the cost of technologies such as microchips and renewable energy has fallen exponentially as they have become more powerful and/or efficient;

(c) **Faster**, in that the new technologies are diffusing ever more rapidly around the world, propelled by Internet connectivity and sharply falling prices;

(d) **Scalable**, in that they often offer small-scale solutions that can be rapidly scaled up to meet human needs for energy, food, clean water, health care and education; and

(e) **Easy to use**, in that they have rendered previously complex, laborious and/or time-consuming tasks, such as searching for patterns in huge data sets, almost effortless, while becoming increasingly transparent to users.

These traits open the possibility of a democratization of technology, making technological innovation an increasingly bottom-up process. Globally, the digitalization of economic activities has been accelerated by expanding access to high-speed broadband and drastic reductions in the cost of ICT equipment and software: the cost of 1 gigabyte of hard drive storage capacity was just $0.02 in 2016, compared with more than $400,000 in 1980 (UNCTAD, 2017b).

Harnessing new technologies and innovations could thus be transformative in achieving the Sustainable Development Goals and producing more prosperous, sustainable, healthy and inclusive societies. They offer governments seeking to meet the challenges of the Sustainable Development Goals with limited resources an opportunity to achieve “more with less” by supporting their use and developing new innovation ecosystems that offer flexibility while reducing costs and risks. They can allow new solutions to be found and deployed, and failures to be identified and triaged more quickly, reducing the risk of technology investment “bets” proving costly and of technologies being obsolete before they come to fruition.

However, the proliferation of new technologies threatens to outpace the ability of societies and policymakers to adapt to the changes they create. The rate of turnover of technology platforms can reportedly be as short as 5–7 years – half the 10–15 years it may take society and regulatory measures to adapt (Friedman, 2016).[2] This has created widespread anxiety, causing ambivalence to or rejection of technological advances such as gene editing and deep learning[3] in artificial intelligence. If societies are to cope better with the accelerated pace and broadened scope of technological change, policymakers will need to develop plans based on technological foresight and assessment of potentially

2 It should not be assumed that technological change systematically precedes social and institutional change. The reverse sequence is equally possible, with no less significant effects for socioeconomic transformation.

3 Deep learning allows computational models that are composed of multiple processing layers to learn representations of data with multiple levels of abstraction. These methods have dramatically improved the state of the art in speech recognition, visual object recognition, object detection and many other domains, such as drug discovery and genomics. Deep learning discovers intricate structure in large data sets by using the backpropagation algorithm to indicate how a machine should change its internal parameters that are used to compute the representation in each layer from the representation in the previous layer. Deep convolutional nets have brought about breakthroughs in processing images, video, speech and audio, whereas recurrent nets have shone light on sequential data such as text and speech (LeCun et al, 2015).

**Table 1.1 Technology clusters discussed in this report as possible contributions to Sustainable Development Goals**

| Technology cluster | Frontier technologies for the Sustainable Development Goals until 2030 | Opportunities in Sustainable Development Goal areas |
|---|---|---|
| Biotech | Integrated disciplines in biotechnology of synthetic biology, systems biology and functional genomics for applications in health (e.g. integration of "omics" applications, customized DNA sequences), industry (e.g. bio-catalysis) and agriculture | Maintenance of genetic diversity of seeds, cultivated plants through utilization of genetic research (Sustainable Development Goal 2),<br>research and development of vaccines and medicines for the treatment of communicable and noncommunicable disease (Goal 3), and cleaner energy services (Goal 7) |
| Digital technologies | Internet of Things (IoT), 5G mobile phones, 3D printing, massive open online courses, data sharing technologies, emerging models for financial transactions (e.g. mobile money, digital currency exchanges, digital wallets), open science, smart agriculture and electricity grids | Manufacturing (Goal 9),<br>resource efficiency (Goals 6 and 7),<br>countries' extension of financial inclusion in developing countries (Goal 10) and resilient agriculture practices (Goal 2) |
| Nano-tech | Solar energy (nonmaterial solar cells), and organic and inorganic nanomaterials (e.g. graphene and carbon nanotubes) | Energy efficiency, increase of renewables in global energy mix (Goal 7), improvement of water quality and safe drinking water (Goal 6), and medical and pharmaceutical industries (Goal 3) |
| Green technologies | Energy: modern cooking stoves, advances in battery technology, smart grids, solar desalination, third-generation solar photovoltaic (PV) (copper, zinc, tin, sulfide, perovskite solar cells, nanomaterials such as organic solar PVs, and quantum dot solar cells), and<br>ICT and water management | Environment, climate, biodiversity, sustainable production and consumption (Goal 7), clean air and water (Goal 6), and sustainable agriculture (Goal 2) |

*Source:* Adapted from United Nations (2016), chapter 3.

disruptive effects of technology over years and even decades. This could also involve increasing policy experimentation and facilitating shorter, more responsive innovation cycles.

Key features of the frontier technologies commonly associated with the Fourth Industrial Revolution need to be understood if developing countries are to reap benefits for sustainable development. Table 1.1 is not meant to be an exhaustive list, but rather outlines four key technology clusters discussed in this report, with the potential to contribute to achievement of the Sustainable Development Goals – biotech, digital, nano and green technologies – and their attendant risks.

## C. DISTINGUISHING FEATURES OF FRONTIER TECHNOLOGIES

The pace of development and adoption of new technologies has accelerated dramatically in recent decades (figure 1.1).[4] There are several reasons for this, which are likely to maintain this acceleration into the future: technologies building on each other, "Moore's Law", technology convergence, declining costs, multiple platforms and reduced entry costs.

### 1. Technologies building on each other

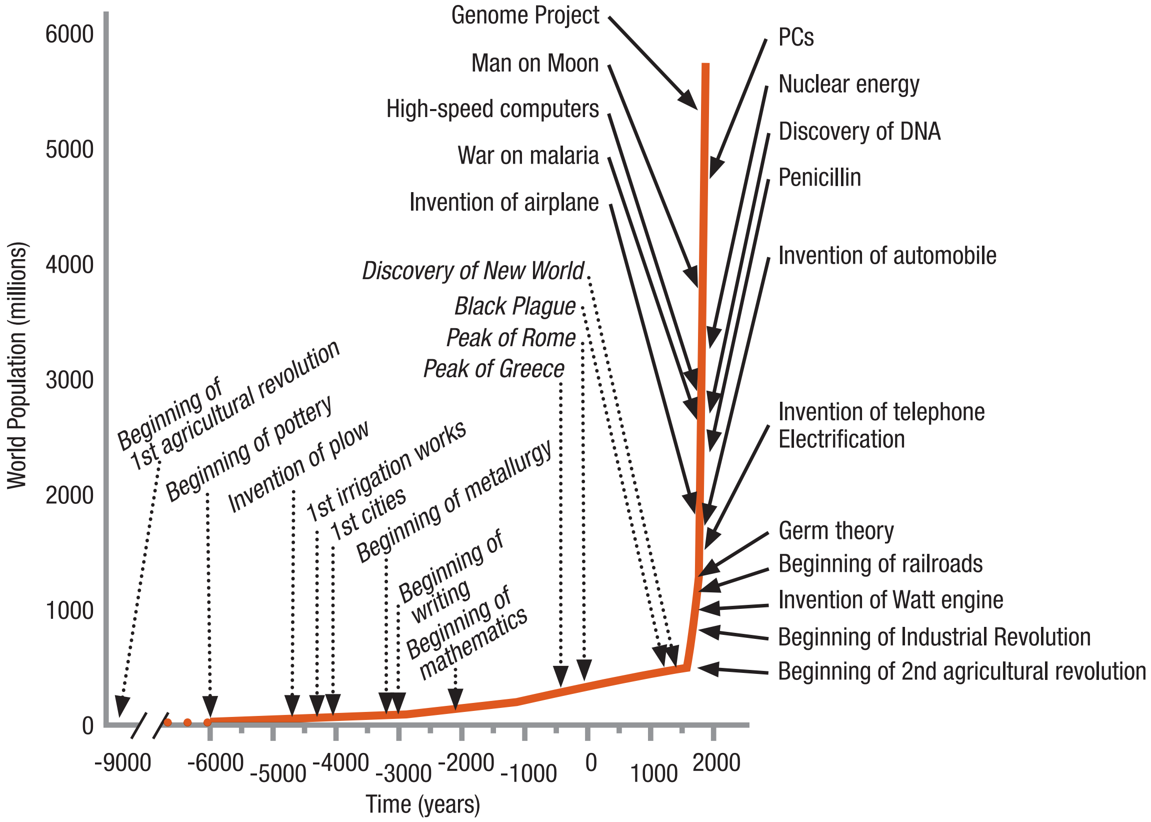
Since all technologies build on previous scientific discoveries and technological developments, the rate of development of new technologies increases as more ones are developed. The invention of the steam engine, for example, led to transformations of transportation and factories, resulting in economic, social and geopolitical transformations that set the stage for more technological development. Similarly, the harnessing of electricity led to electrification of factories and homes, the telegraph, the telephone, radio and television, and ultimately modern electronics. Such inventions have transformed the world over the last century, radically changing manufacturing methods, business models, trade, government and media.

### 2. Moore's Law

The pace of development and adoption of technologies has been accelerated exponentially by "Moore's Law", named after Intel co-founder Gordon Moore, who predicted in 1965 that the processing power of microchips would double every 18–24 months. This

4 Robert Gordon notes that technology innovations after 1870 included an energy revolution with the exploitation of oil and the harnessing of electricity, and the development of the internal combustion engine. "These led in turn to the creation of machines: the electric light, the telephone, the radio, the refrigerator, the washing machine, the automobiles and the aircraft. They resulted in the transformation of lives via urbanization and the grid-connected home. These then drove an education revolution, as the economy demanded literate and disciplined workers" (Gordon, 2016: chapter 1).

**Figure 1.1. Technological advances build on previous technological advances**




*Source:* UNCTAD secretariat, adapted from Fogel, 1999, p. 2.

"law" of exponential growth has held broadly true for the subsequent 50 years, leading to a vast increase in capability and significant cost reductions.

Moore's Law has driven major cost reductions across much of the digitized realm. While it is a matter of debate how long it will continue in the development of microchips (see, for example, Anthony, 2016; Borwein and Bailey, 2015; Huang, 2017; Simonite, 2016),[5] the impact of computing power is expected to continue to grow exponentially, powered by increasingly powerful

5 Jensen Huang (CEO of Nvidia, maker of graphics processor unit chips that are powering artificial intelligence) argues that graphics processor units are picking up where Moore's Law leaves off (Huang, 2017).

**Box 1.1 Quantum computing**

Quantum computers are not just faster computers, but rather they approach problem solving in a fundamentally different way. For problems like decryption, which have potentially billions or trillions of possible combinations, classical computers require testing combinations sequentially, while a quantum computer could try all combinations simultaneously to find the key. One simulation by Microsoft indicated that a factoring problem that would take 31,000 years to solve on a conventional computer could be resolved in a matter of seconds on a quantum computer. When general-purpose quantum computers become available, much, if not most, current encryption, including on the Internet, could be subject to nearly instantaneous decryption. Quantum computers could also mark a new age in solving intractable problems. A quantum computer could simultaneously explore thousands of possible molecular combinations for a new material or drug to find the best combination in short order. It could solve such challenges as creating a room temperature superconductor, accurately and in detail modelling climate change, and finding a catalyst to pull $CO_2$ from the air. Although the first quantum computers will be very large, they could eventually be very small and provide immense new power to individuals and IoT.

algorithms (software), cloud computing, increasingly powerful machine learning and deep learning, new types of microprocessors, and improvements in quantum computing, which is expected to be commercialized in the next decade (box 1.1).

## 3. Technology convergence

Technologies are converging through the increasing use of digital platforms to produce new combinatory technologies, which are expected to continue to accelerate the pace of technological change, resulting in simultaneous technology-induced disruptive changes across multiple sectors. Such changes quickly spread worldwide, with important ramifications throughout society, relentlessly resetting "the state of the art". They are changing how people communicate, work, organize their social life or monitor their health. They are also changing business organization and government. Examples of technological convergence include: personalized medicine enabled by large databases of disease states and patient information; rapid and parallel gene sequencing; ability to design and test new drugs using computer simulations; wearable personal medical monitoring devices; new nanotech-enabled miniaturized, highly sensitive chemical and biological sensors; fabrics that incorporate electronics, power sources and optical fibres; and water purification systems based on nanostructured, activated filters and membranes.[6]

Convergence is taking place not only in terms of technology but also in terms of platforms, interests and investments. In agriculture, for example, the convergence of mobile and cloud computing, sensor deployment in machinery, genomics and other technologies promises to enable quantum leaps in precision farming. The same convergence is also motivating commercial alliances and mergers among companies in sectors such as farming equipment, computing and seed production. The possibilities to achieve higher yields with fewer inputs, and thus a lighter environmental burden, are significant. At the same time, there are concerns about the concentration of market power that may result from the possibility to gather such vast amounts and combinations of different data sets through such mergers and acquisitions.

## 4. Declining costs

The cost of digitally-enabled devices tends to drop precipitously. The cost of smartphones is expected to fall to as little as $30 over the next five years, "putting in the hands of all but the poorest of the poor the power of a connected supercomputer" with "more computing power than our own brains" by 2023 (Wadhwa with Salkever, 2017: 15). Cost reductions are also affecting the energy sector, notably in solar photovoltaic (PV) power, which has become cost-competitive with fossil-fuel generation, and in electric vehicles and batteries.[7]

In some cases, digital technologies are reducing marginal production costs almost to zero. For example, while a book, CD or DVD entails the cost of materials, printing, shipping, etc., the marginal cost of an e-book or streaming is virtually zero (Rifkin, 2014). This tendency toward "zero marginal cost" accelerates the diffusion of such technologies, further accelerating technological development and innovation.

## 5. Multiple platforms

Two "platforms of platforms" have played a central role in accelerating technological change: the Internet, enabling global mobile connectivity; and the global positioning system (GPS), which functions as a source of geolocation for millions of apps. These two platforms have allowed new subsidiary platforms to be built, driving further technological innovation and business creation, as start-up businesses exploit an ecosystem of "apps" based on smartphone platforms.

Platforms built on the Internet are creating new opportunities for entrepreneurs all over the world to start new technology-based companies, and for both start-ups and existing SMEs to reach global markets. While global trade has stagnated, and cross-border capital flows have declined since the 2008 financial crisis, there

6 Issues Paper on Strategic Foresight for the Post-2015 Development Agenda. Available at http://unctad.org/meetings/en/SessionalDocuments/CSTD_2014_Issuespaper_Theme1_Post2015_en.pdf (accessed on 15 March 2018).

7 Recent findings show a strong tendency, across different types of technologies (including chemical, hardware, energy, and other) towards exponential growth rates in production and corresponding decreases in cost. However, the unique cost and performance characteristics of specific technologies, coupled with regulatory and other policies, may result in them not exhibiting these features (Nagy et al., 2013; Ball, 2013).

has been an exponential increase in flows of data and information, with significant implications for job creation in developing countries and connectivity of their economies to the global marketplace and to global knowledge, education and entertainment (Manyika et al., 2016).

The world's population is directly connected to this data flow, as access to technology has become increasingly "democratized". In the fourth quarter of 2016, there were 7.7 billion mobile phone subscriptions, 5.2 billion individual subscribers, and 4.3 billion mobile broadband subscriptions worldwide (57 per cent of the world population).[8] By 2021, it is predicted that there will be 9 billion mobile subscriptions, 7.7 billion broadband mobile subscriptions, and 6.6 billion smartphone subscriptions (including an additional 730 million subscribers in the Middle East and Africa, and 230 million in Latin America). By 2025, nearly every person on the planet is expected have access to Internet-connected mobile devices.[9]

### 6. Reduced entry costs

These platforms have also led to a sharp reduction in entry costs for scientific experimentation and business creation, leading to a worldwide proliferation of start-ups leveraging the Internet, cloud computing, artificial intelligence, 3D printing, drones, apps and computational biology. The costs and labour requirements of starting an Internet business have been reduced by cloud-based computing and open source software, which avert the need for major investment in servers and software.[10] The main non-labour costs of a start-up are a laptop computer and an Internet connection, together with cloud-based computing services for a software company or a 3D printer for a company producing material products.

8 Mobile Subscriptions, Ericsson Mobility Report, Fourth Quarter 2016, available at www.ericsson.com/assets/local/mobility-report/documents/2017/emr-interim-february-2017.pdf (accessed 15 March 2018); Mobile Subscriptions, Ericsson Mobility Report, First Quarter 2016, available at https://www.ericsson.com/en/mobility-report/reports (accessed 15 March 2018).

9 Mobile Subscriptions, Ericsson Mobility Report, First Quarter 2016, available at https://www.ericsson.com/en/mobility-report/reports (accessed 15 March 2018).

10 The monthly cost of storing one gigabyte of data in the cloud on Amazon Web Services fell from $19.00 in 2000 to $0.16 in 2011 (www.slideshare.net/The_Cambrian_Cloud/diminishing-startup-costs) and less than $0.03 in 2016 (https://cloud.google.com/storage/pricing).

## D. KEY TECHNOLOGIES AND THEIR POTENTIAL CONTRIBUTIONS TO SUSTAINABLE DEVELOPMENT

The two key features of frontier technologies have been digitalization and connectivity. The rapid connection of most of the global population through the mobile Internet is creating an extraordinary range of new opportunities to exploit the vast array of digitally-enabled frontier technologies to address the Sustainable Development Goals in virtually every country.

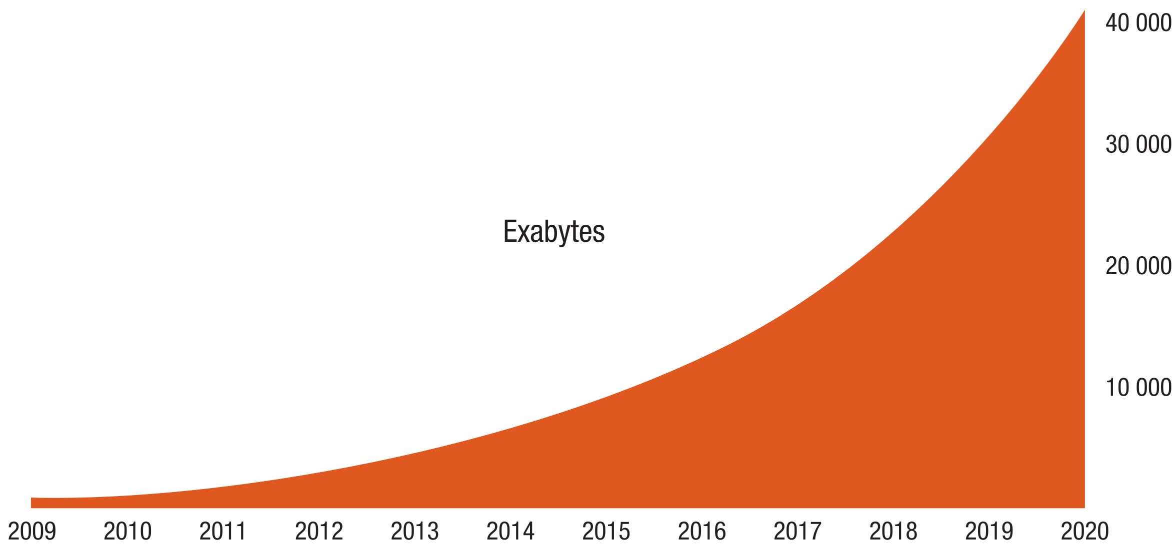
### 1. Big data, the Internet of Things and artificial intelligence

Big data and IoT are new digital developments that make it possible to optimize business operations and facilitate the creation of new products, services and industries. The possibility of collecting unlimited amounts of data through Internet-connected sensors and monitoring of the web and social media allows prediction of demand, estimation of rural incomes (based on mobile phone activity) and anticipation of civil unrest. While such technologies add to the existing toolkit for development, the availability of fine-grained and increasingly personal data also introduces new risks (see section D.2). Such technologies therefore merit attention from policymakers.

It is predicted that data will grow exponentially from around 3 zettabytes in 2013 to approximately 40 zettabytes by 2020 (figure 1.2).[11] **Big data** allows value to be created in new ways and insights to be made on a large scale, impacting organizations, markets and government–citizen relationships. The gathering and analysis of big data can be used proactively for

11 This is an estimate by International Data Corporation (IDC) of all the digital data created, replicated and consumed in a single year. Examples of data included in the estimate include "images and videos on mobile phones uploaded to YouTube, digital movies populating the pixels of our high-definition TVs, banking data swiped in an ATM, security footage at airports and major events such as the Olympic Games, subatomic collisions recorded by the Large Hadron Collider at CERN, transponders recording highway tolls, voice calls zipping through digital phone lines, and texting as a widespread means of communications" (IDC, 2012). An exabyte is 1,000,000,000,000,000,000 bytes, and a zettabyte is 1,000 exabytes.

**Figure 1.2 Growth of big data 2010–2020**




*Source:* IDC (2012).

administrative and commercial purposes, or passively through the digital exhausts of the World Wide Web (web pages and social media), sensor-based devices and data logs generated by computing devices (UNCTAD, 2015a:7).

Big data analysis can help to manage or resolve critical global issues, assist in the creation of new scientific breakthroughs, advance human health, provide real-time streams of information (e.g. on disease outbreaks or traffic conditions), monitor natural systems, improve the efficiency of resource use, and support decision-making by business people, policymakers and civil society. The ascendancy of big data is based on a move from sampling data to analysing all the data, while facilitating segmentation and targeting within a dataset.

**The Internet of Things** (IoT) allows the condition and actions of connected objects and machines to be monitored and managed, while connected sensors can monitor the natural world, animals and people (Manyika et al., 2015a). In the IoT, objects exchange data with other connected objects, systems and users through the Internet (Catholic Relief Services, 2015). IoT devices include devices to monitor eating, sleeping or fitness habits using sensors; to control home appliances using mobile phones; and to monitor soil conditions in order to improve agricultural productivity using sensors (Dora, 2015a). The number of such devices is expected to rise from 15 billion in 2015 to 50 billion by 2020, a third of these being computers, smartphones, televisions and mobile devices. The market, currently valued at $655.8 billion, is expected to reach $1.7 trillion in 2020 and between $3.9 trillion and $11.1 trillion by 2025 (see table 1.2) (Dora, 2015a; Zawya, 2015; CXOToday.com, 2015:7).

The IoT has the potential to create value in a wide range of sectors, including health, retailing, construction and trade (Manyika et al., 2015a). It could also potentially address inefficiencies in manufacturing and related processes.

In the last few years, **artificial intelligence** has become a major focus of attention for technologists, investors, governments and futurists. Since it was first proposed more than 60 years ago, artificial intelligence has experienced periods of progress but also of stagnation, when it has been virtually sidetracked while other technologies advanced exponentially. However, recent breakthroughs have led to major advances, driven by machine learning and deep learning, facilitated by access to huge amounts of big data, cheap and massive cloud computing, and advanced microprocessors (Kelly, 2016:38–40). Artificial intelligence now includes image recognition that exceeds human capabilities and greatly improves language translation, including voice translation through natural language processing, and has proved more accurate than doctors at diagnosing some cancers.

**Table 1.2. Potential economic impact of Internet of Things in 2025**[12]

| Setting | Size in 2025[1] ($ billion, adjusted to 2015 dollars; Low estimate – High estimate) Total = $3.9 trillion–11.1 trillion | Major applications |
|---|---|---|
| Human | 170–1,590 | Monitoring and managing illness, improving wellness |
| Home | 200–350 | Energy management, safety and security, chore automation, usage-based design of appliances |
| Retail environments | 410–1,160 | Automated checkout, layout optimization, smart CRM, in-store personalized promotions, inventory shrinkage prevention |
| Offices | 70–150 | Organizational redesign and worker monitoring, augmented reality for training, energy monitoring, building security |
| Factories | 1,210–3,700 | Operations optimization, predictive maintenance, inventory optimization, health and safety |
| Worksites | 160–930 | Operations optimization, equipment maintenance, health and safety, IoT-enabled R&D |
| Vehicles | 210–740 | Condition-based maintenance, reduced insurance |
| Cities | 930–1,660 | Public safety and health, traffic control, resource management |
| Outside | 560–850 | Logistics routing, autonomous cars and trucks, navigation |

[1] Includes sized applications only.
*Note:* Numbers may not sum due to rounding.

Some Asian developing countries, notably China and the Republic of Korea (box 1.2), are already making rapid progress in automating their industries; and declining costs and increasing capabilities could make it easier for SMEs to do so more widely. [12]

## a. *Big data and Internet of Things in health care*

In countries with functional health systems, big data and IoT could contribute to improving health care by allowing treatments to be personalized, clinical data to be collected beyond the occasional patient–doctor visit, disease progression to be detected earlier (at the individual and community levels) and treated proactively, and more effective cures to be found for intractable conditions. Clinical trials can also be facilitated by applying statistical tools and algorithms to mine patient data, and by recommending better protocol designs (Manyika et al., 2015b), while mapping data can strengthen responses to disease outbreaks. During a typhoid outbreak in Uganda, for example, the Ministry of Health used data-mapping applications to facilitate decision-making on the allocation of medicine and mobilization of health teams (box 1.3).

Big data and IoT have also been used in medical research. For example, researchers from the Institute for Computational Health Sciences are using freely available clinical big data released as part of the

[12] Manyika et al. (2015a).

**Box 1.2 Increasing automation in China**

China is rapidly expanding its deployment of industrial robots as a result of demographic factors, since its working-age population is declining, but also due to the increasing cost of labour, which is eroding its advantage as a low-cost production country. Moreover, the Government is encouraging the use of robots through the industrial strategy called “Made in China 2025”.. UNCTAD (2016b) notes that China is also evolving as a major producer of industrial robots, as a result of its lower costs and better ability to understand the needs of Chinese customers. In this context, the Government released a guideline to triple annual production of industrial robots by 2020. In 2015, China sold around 68,000 robots, which was 20 per cent above its previous year’s figure, and plans to produce up to 400,000 units by 2019 (International Federation of Robotics, 2016a). However, Chinese technology in producing robots still lags far behind that of the foreign leading robot-making companies. And Chinese producers need to import a large part of their components (Wübbeke et al., 2016).

The increasing automation in China could have a significant impact on the labour force. A remarkable recent example is that of Foxconn Electronics, a major electronics assembly company, with its massive automation drive in Chinese factories in three phases. In the end, entire factories would be automated, with a small number of workers in production, logistics, testing and inspection processes (Tech Times, 2016; Forbes, 2016). As a result of increasing automation in China, prospects for cheap labour production of manufactures, which was taking place in China and moving into other developing countries, could be vanishing; automation will allow China to continue to produce these goods. This suggests that lower-income countries that could have expected to fill the gap left by China in low-cost manufacturing production and exports as it upgrades its technology content (flying geese pattern) are seeing export-led manufacturing fading away as a possible industrial development strategy that could help in generating much-needed jobs.

*Source:* UNCTAD secretariat.

**Box 1.3 Data visualization and interactive mapping to support response to disease outbreak in Uganda**

In 2015, Uganda had a typhoid outbreak. The Ugandan Ministry of Health’s district office collected data at the health centres where typhoid cases were treated. In order to use this information effectively for a disease response, Pulse Lab Kampala was invited to utilize interactive data visualization tools to help present dynamic information about case data and risk factors in support of managing the outbreak. This, in turn, helped reveal clusters of infection through interactive maps at the district, sub-county and individual health facility levels. Furthermore, interactive mapping tools provide the ability to show infection rate data, along with information about risk factors, and thereby helped understanding of the patterns of transmission. As a result, the visualizations contribute in the assessment for decision-making regarding the allocation of medicine and mobilization of health teams (United Nations Global Pulse, 2015).

*Source:* United Nations Global Pulse, 2015

United States National Institutes of Health funding requirements to study the potential of existing drugs to treat other medical conditions.[13]

### *b. Big data and Internet of Things in agriculture*

Big data and IoT are also creating new possibilities in agriculture, and may provide useful tools to increase food security, for example, by allowing farmers to identify the best time to plant by monitoring soil conditions, and by facilitating insurance (box 1.4). In India, the CropIn start-up provides analytics and software solutions for crop management, and has developed a vegetation index using satellite imagery that provides support to farmers in decision-making to ensure crop health (see box 1.5). At the same time, as indicated in the above discussion of technological and business convergence, digitalization (for example, the digitalization of genetic material), big data and IoT may enable an increase in the relative market power of large corporations with potential effects on agricultural organization and practices in developing countries. It also raises issues related to the protection of genetic resources (see chapter III).

[13] The Institute for Computational Health Sciences was established by the University of California–San Francisco in 2013, to harness the power of big data to accelerate the development of effective cures for patients worldwide.

**Box 1.4 Big data to provide insurance for small-scale farmers in Africa**

The Kenya-based insurance company UAP partnered with Syngenta (providers of farm products) and Safaricom (Kenyan telecom operator) to launch the Kilimo Salama (Safe Farming) microinsurance project. Historically, insurance has had many challenges in the Kenyan context, including spam advertising through mobile phones, difficulties claiming insurance money, aggressive, large sales teams and inefficient claims processes. Based on big data from over three decades of climate and crop trends, UAP can determine the appropriate compensation plan for the current year without the need to assess individual cases. This weather index insurance scheme can automatically process insurance claims when the rainfall exceeds an average at a given value. As the first microinsurance product in the world to be fully distributed and implemented over a mobile phone network, farmers can receive insurance policy numbers and premium receipts via short message service (SMS) and insurance payouts via the M-PESA platform. The project was spun off as the company Acre Africa and in 2014 insured a total of 233,795 farmers in Kenya and Rwanda.

*Sources:* International Finance Corporation (n.d.); Macharia (2013); http://acreafrica.com.

**Box 1.5 Big data for agriculture in India**

The company CropIn was created to provide software solutions and analytics for crop management. Today, customers for this customized cloud application are large companies that have invested in food processing and agriculture, and had to depend heavily on their field staff to connect with farmers. The CropIn application tags crops and tracks their development until harvest. The system, when fed with information pertaining to sowing time and seed type, provides crop development information at various stages of production. CropIn is used by 40 companies, including Pepsico and Mahindra Agri, and benefits 100,000 farmers across 15 states in India.

*Source:* Singh (2015).

### *c. Internet of Things in water management*

Advances in ICTs could also facilitate the production and efficient distribution of water – a perennial challenge for national, regional and local governments – especially in urban areas. Water management can be improved by IoT devices such as sensors, meters and mobile phones (table 1.3), although the collection, analysis and sharing of data on water usage must take account of privacy, confidentiality and security considerations. The use of a wireless sensor network to monitor and study the water quality in Bangladesh is described in box 1.6.

**Table 1.3 Major areas for Internet of Things devices in water management**

| | |
|---|---|
| **Mapping of water resources and weather forecasting**<br>• Remote sensing from satellites<br>• In-situ terrestrial sensing systems<br>• Geographical Information Systems<br>• Sensor networks and the Internet | **Asset management for the water distribution network**<br>• Buried asset identification and electronic tagging<br>• Smart pipes<br>• Just-in-time repairs/real-time risk assessment |
| **Setting up early warning systems and meeting water demand in cities of the future**<br>• Rain/storm water harvesting<br>• Flood management<br>• Managed aquifer recharge<br>• Smart metering<br>• Process knowledge systems | **Just-in-time irrigation in agriculture and landscaping**<br>• Geographical Information Systems<br>• Sensors networks and the Internet |

*Source:* Singh (2015).

**Box 1.6 Water quality monitoring using Internet of Things: Bangladesh**

In Bangladesh, tens of millions of people in the Ganges Delta are faced with the threat of drinking groundwater that is contaminated with arsenic. Testing and analysis of arsenic contamination is found to be technically difficult and expensive. IoT can be a lifesaver in this context. Wireless sensor networks were deployed, mainly to facilitate better understanding of the factors controlling arsenic mobilization to groundwater. A manual arsenic sensor, combined with the data collected from the sensor network, has been used to get a better understanding of the groundwater chemistry at shallow depth. Scientists associated with this project recommended that wireless sensor networks be deployed as a shared resource in developing countries to address critical development al challenges.

*Source:* Zennaro et al. (2008):67.

### *d. Big data for development indicators*

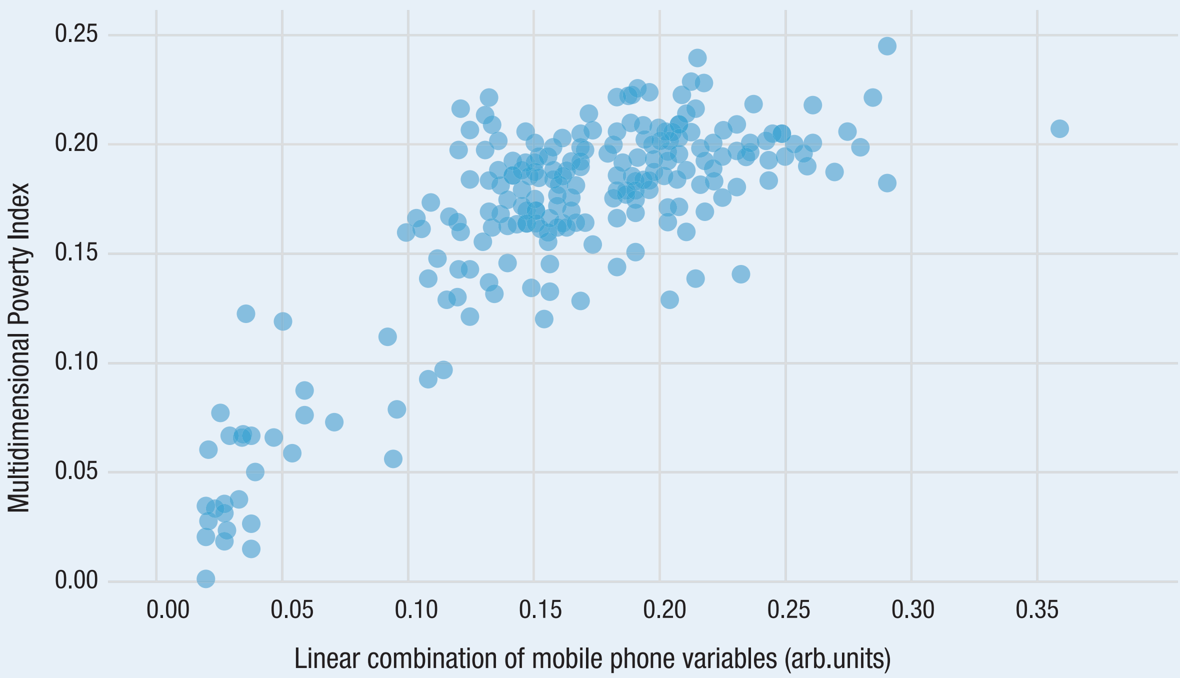
Monitoring progress towards the Sustainable Development Goals requires collecting data on development indicators (United Nations, 2015), and international organizations, researchers and private sector companies are harnessing big data to this end.14 IoT devices and big data hosted on the Internet may provide new opportunities to measure development. For example, a study carried out by the United Nations World Food Programme (WFP) using mobile phone data found that airtime could serve as a proxy indicator for food expenditure (box 1.7). Internet search data may also help to predict social and economic trends. For example, a correlation has been found between Google Trends indices (real-time daily and weekly index of the volume of queries that users enter into Google) and various economic indicators that are potentially helpful to short-term economic forecasting (Choi and Varian, 2012).

However, while such big data-derived indicators may help to create additional tools to measure and evaluate progress towards the Sustainable Development Goals, it remains to be seen whether they will prove as accurate as research and pilot projects suggest. Big data algorithms cannot be taken at face value but must be critically examined, especially when used to generate complementary indicators for development efforts, and the veracity and accuracy of big data and IoT-derived data must be continuously monitored. Human capabilities are critical to assessing and evaluating the accuracy of big data algorithms and understanding when the results are useful or misleading.

[14] For example, the United Nations Statistical Commission and United Nations Global Pulse.

**Box 1.7. Big data for estimating food security in Rwanda**

A study in Rwanda by WFP, *Université Catholique de Louvain* and Real Impact Analytics of Belgium investigated the potential of mobile phone data as a proxy indicator for food security, by comparing the results of a nationwide household survey conducted by WFP with data on airtime credit purchases ("top-ups") and mobile phone activity. A strong correlation was found between airtime credit purchases and consumption of several food items, including vitamin-rich vegetables, meat and cereals, suggesting that they could serve as a proxy indicator for these expenditures across locations. Models based on mobile phone activity and airtime credit purchases were also shown to provide accurate estimates of multidimensional poverty, as shown in the figure below, suggesting that they might have a role to play in monitoring systems.




*Source:* UN Global Pulse (2014):8.

Sectoral ministries – for example of agriculture, education, fisheries, water and sanitation – should consider whether and how big data and IoT devices might enhance their existing plans and strategies. Governments may consider developing a "national big data strategy" to harness the potential of big data towards national development, in collaboration with other stakeholders, such as the Big Data Joint Laboratory in China (box 1.8). Such a strategy, linked with the overall national development framework, can allow governments to integrate big data analysis into national strategies, as in Malaysia (box 1.9). Governments might also consider creating cross-sectoral units staffed by data scientists to apply big data and IoT to problem-solving across a range of applications. In the past few years, countries such as Singapore and the United States have created chief data scientist positions at the national level, while many cities are creating similar positions to harness data to improve internal government processes and services.

**Box 1.8 Harnessing big data to support development goals**

The Big Data Joint Laboratory is a collaborative initiative launched in 2014 as a partnership between the United Nations Development Programme (UNDP), China and Baidu to harness big data for development goals. Stakeholders in development and big data experts from UNDP, Baidu, the private sector, government, academia and civil society are expected to use the Laboratory to produce prototype ideas for testing and implementation, and Baidu's big data engine will be used to identify which data offer potential for the formulation and implementation of development strategies. An inaugural product is an e-waste recycling "Light App" that helps to streamline the recycling of electronic waste.

*Source:* UNDP (2014).

**Box 1.9 National Big Data Analysis Initiative, Malaysia**

In 2014, Malaysia launched a National Big Data Analysis (BDA) Initiative, linked with the Digital Malaysia Programme (the national ICT strategy), with the aim of transforming Malaysia into a regional hub for big data analysis. The objectives are to widen the use of BDA in all sectors, to catalyse its use in the public sector and to build the BDA industry, through short-, medium- and long-term policy actions. Short-term actions include developing a BDA framework and government pilot projects. Five main roles have been identified for the Government: open and shared data policy; education; infrastructure; funding; and regulatory changes to remove barriers to BDA innovation. In early 2015, a BDA Innovation Network was launched, and three memoranda of understanding were signed between leading industry and key government partners to establish a network of BDA Innovation Centres of Excellence. In May 2015, a Big Data Digital Government Laboratory was also launched as a public sector hub for BDA technologies.

*Sources:* Available at https://www.mdec.my/news/big-data; and www.mimos.my/paper/malaysias-big-data-drive-continues-mimos-launches-national-lab/.

## 2. 3D printing

Another recent digital development, 3D printing, also offers potential economic, social and environmental benefits for developing countries. Invented three decades ago, 3D printing has become a viable technology for global manufacturers to produce critical parts for airplanes, wind turbines, automobiles and other machines as a result of huge reductions in its costs and complementary developments in computer-aided design, the Internet, new materials for manufacturing and cloud computing (Campbell et al., 2011). The process of 3D printing, which produces objects through a simple process of layering, is sometimes referred to as additive manufacturing, in contrast with traditional (subtractive) manufacturing, which creates parts out of raw materials. As well as global manufacturers, tens of thousands of early adopters are now experimenting with 3D printers or starting mini-manufacturing enterprises (Garrett, 2015:15–16).

As a "platform technology", 3D printing can be used in a range of applications, including health care, aerospace (e.g. printing airplane parts) and construction (e.g. printing houses and large buildings) (Garrett, 2015). It has also been argued that 3D printing could help developing countries to leapfrog into manufacturing and produce large numbers of products on demand with retooling, while using recycled materials and less costly infrastructure (ibid.).

The 3D printing market is expected to grow quickly in the coming years (figure 1.3). Shipments of 3D printers are projected at least to double every year between 2015 and 2018, to reach 2.3 million (ibid.:15), while the Wohlers Report (2014) claims that 3D printing revenues will quadruple, from $3.07 billion in 2013 to $12.8 billion 2018, and exceed $21 billion by 2020 (Ubhaykar, 2015), the growth occurring in both developed and developing countries (Wohlers Associates, 2014).[15]

The 3D printing process has the potential to transform business, especially in manufacturing (box 1.10), opening up opportunities for significantly lower-cost production than conventional factories in developing countries with limited manufacturing capability and heavy reliance on imports of consumer goods (Garrett, 2015). This transformative potential rests on three main elements:

(a) Cost and time savings compared with traditional manufacturing processes;

(b) Potential to manufacture complex, low-volume parts and products; and

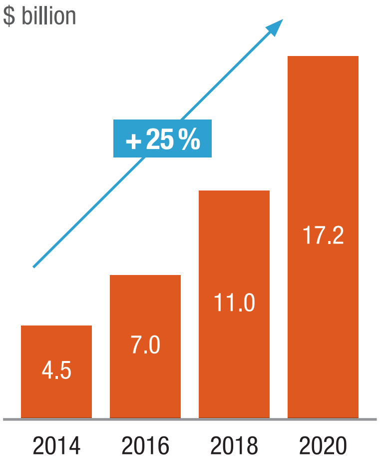
(c) Potential for rapid, iterative prototyping in manufacturing enterprises.

The 3D printing technologies could also help to reduce carbon emissions by producing goods in a single process, thus averting the need for multiple parts to be transported (UNCTAD, 2016a), while reducing resource use by using only the material it needs (Dewey, 2015). Ultimately, concerted efforts and innovation will be required to maximize the potential environmental benefits and minimize environmental costs if 3D printing is to contribute to more environmentally sustainable development.

[15] Wohlers Associates, Inc. is considered an authoritative source of information on the additive manufacturing market. Another estimate, from Scarlett Inc., is that the 3D printing industry will grow from $3.8 billion in 2012 to more than $17 billion in 2020 (Dewey, 2015).

**Figure 1.3 The use of 3D printing is expected to grow[16]**

**Global 3D industry market for hardware, supplies, and services**
$ billion




**3D printing market**

| Sector | 2014 | Five-year CAGR |
|---|---|---|
| Aerospace (including defense) | $0.8 billion 18% | 15–20% |
| Industrial (including construction) | $0.8 billion 18% | 15–20% |
| Health care | $0.7 billion 15-17% | 20–25% |
| Automotive | $0.5 billion 12% | 15–20% |
| Jewelry | $0.5 billion 12% | 25–30% |
| Energy | Less than 5% | 30–35% |
| Other (many sectors) | Less than 20% | 20–25% |
| **Total** | **$4.5 billion** | **25%** |

[16] According to the Wohlers Report, SmarTech Markets, Credit Suisse and A.T. Kearney Analysis.

**Box 1.10 Examples of 3D printing**

In one example, 3D printing has been applied to cost-efficient production in the automotive industry. The Chinese company Sanya Si Hai 3D has produced a two-seater compact sedan that can reach speeds of 40 km/h (see figure). It took only $1,700 and five days to build this car.

Also, we see that Tata Motors has incorporated 3D printing technologies in their processes to reduce its turnaround times from months to weeks, and thus iterate more in design. Instead of handing off computer-aided design models to manufacturers who use traditional machinery, the computer-aided design models are used directly to 3D print parts and validate designs that are difficult to visualize on a 2D screen.

*Source:* Ubhaykar, 2015.

### a. *Applications of 3D printing: Health care*

The 3D printing technologies are allowing the development of some low-cost prosthetics. South Africa's Centre for Rapid Prototyping and Manufacturing at the Central University of Technology, Free State, for example, has 3D-printed titanium jaws for at least a dozen patients at Kimberley Hospital (APANEWS, 2014; Diamond Fields Advertiser, 2015). However, there are important limitations: most 3D printers can only use one material at a time, rather than the combination of materials generally required for prosthetic limbs, for example; and 3D-printed models may not be able to reconstruct the interface between prosthetic limbs and soft tissue (Andrews, 2013). A clear understanding of such trade-offs is essential in the consideration of such applications.

### b. *Applications of 3D printing: Construction of buildings*

Rapid urbanization, especially in developing countries, requires new approaches to cost-effective and sustainable housing; and experimentation is underway with the use of 3D printing as a rapid and inexpensive means of constructing buildings. A five-story house has been constructed in an industrial park in Jiangsu Province in China using printing with glass, steel, cement and recycled construction waste (Arch Daily, 2015).

The 3D printing process offers faster and more accurate construction with lower labour costs, waste generation, and health and safety risks. However, in considering 3D printing as a means of addressing housing and urbanization needs, it is important also to consider potential effects on employment in the construction industry, the implications for the types of materials used in construction, and the risk of errors in digital models being translated into printing and construction (Husseini, 2014).

### c. *Applications of 3D printing: Education*

The 3D printing process is also being used as a tool for primary, secondary and post-secondary education, to make abstract concepts concrete for students to explore. In India, for example, students are 3D printing historical artefacts, organ parts, cities, dinosaurs and art projects (Kohli, 2015; India Education Diary, 2015). Collaborative efforts between private firms and nonprofit organizations to digitize diagrams and educational images for the visually impaired as 3D models are also showing positive results (Dataquest, 2015). Fabrication laboratories provide another example of 3D printing technologies as experimental learning spaces for local innovation systems (box 1.11). However, integrating 3D printers into education also requires upgrading of the capacities of teachers to create and print 3D models and to assess the suitability of such technology to existing learning strategies. Box 1.11 gives an example of 3D printers as tools for driving local innovation in universities and schools.

**Box 1.11 Fabrication laboratories as experimental learning spaces for local innovation systems**

While 3D printing technology has the potential to promote innovation, design and tool-creation capacity in developing countries, potentially improving livelihoods and contributing to economic empowerment, its deployment is usually limited to universities, in specialist research centres such as Fabrication Laboratories (FabLabs).

FabLabs, found in both developed and developing countries, are small-scale workshops equipped to offer digital fabrication for individuals or small-sized companies. FabLab Nairobi, for example, was established as part of the University of Nairobi's Mechanical Engineering Department to promote local innovation systems in Kenya, and introduced 3D printing capabilities in 2012. It is part of an international network of FabLabs initiated by the Massachusetts Institute of Technology. Projects developed within FabLab Nairobi include a sustainable sanitation solution for slum areas and a vein-finder device to help administration of intravenous injections in infants. In the United Republic of Tanzania, the innovation think tank Buni Hub is in the process of establishing a FabLab with 3D printers in cooperation with the Finnish Government. They plan to recycle the tons of e-waste generated annually into 3D printers, and to use 3D printers to create teaching aids for primary and secondary schools.

*Sources*: Ishengoma and Mtaho (2014); VOA News (2014); 3Ders.org (2015); 3Ders.org (2011); Buni (n.d.) http://buni.or.tz (accessed 15 March 2018).

## 3. Biotechnology and health tech

Advances in ICT have allowed an increasing integration of synthetic biology, systems biology and functional genomics into biotechnology. Through convergence of an ever-expanding range of "omics" technologies – genomics, proteomics (proteins), metabolomics (biochemical activity), etc. – computational biology explores the roles, relationships and actions of the various types of molecules that make up the cells of an organism (Emerging Technologies, 2014), allowing the functions of organisms to be better understood, from the molecular level to the system level, and advancing biotechnology applications. The cost of sequencing a complete human genome has fallen faster even than implied by Moore's Law (section C.2) to around $1,000, and is expected to cost no more than a regular blood test by the early 2020s (Wadhwa with Salkever, 2017:123–124).

Digitization of biology has also led to an order-of-magnitude decline in the cost of biotech development, for example by allowing experiments to be designed digitally and conducted by cloud-based laboratories for a small fraction of the cost of acquiring laboratory equipment and hiring technicians.[17] Rather than being built from scratch, a synbio product can be constructed from pre-existing modules in the form of downloadable BioBricks – DNA constructs of functioning parts that can be assembled to create new life forms to perform specific functions[18] – and sent to a bioprinter (analogous to a conventional 3D printer) to create a new life form. This does not require knowledge about the functioning of each BioBrick, only about the software needed to design the object and send it to the printer. The resulting organism can be transmitted digitally through the Internet and recreated anywhere.

Gene editing for human medicine and genetic modification of plants and animals are being transformed by clustered regularly interspaced short palindromic repeats (CRISPRs) (box 1.12) (Futurism, 2017), a new and inexpensive tool that

[17] Nordic Apis (2016). The article states that two cloud-based lab companies, Transcript and Emerald Cloud Computing, "are both thriving in this ambitious quest to usher in a new era of **life sciences entrepreneurship**, in which a small cash-strapped team can create and manage a profitable pharmaceutical company from a laptop, much like what can be achieved today in web startups … Their aim is to change the way research is done, dramatically offsetting the ever-increasing costs of clinical trials, automating tedious lab work, and accelerating research by running experiments in parallel. They currently offer common protocols like PCR for genotyping animal samples, DNA/RNA synthesis, and protein extraction. More complex or custom experiments are still better delegated to a CRO [Contract Research Organizations], but in the future all experiments may be conducted in this way."

[18] The BioBricks Foundation (http://biobricks.org/, accessed 15 March 2018) maintains a registry of a growing collection of genetic parts that can be mixed and matched to build synthetic biology devices and systems. BioBrick standard biological parts are DNA sequences of defined structure and function that share a common interface and are designed to be incorporated into living cells such as E. coli to construct new biological systems. Many of these parts are created through the International Genetic Engineered Machine Competition for young scientists and engineers. The nonprofit company Addgene is another source of downloadable molecular tools (Ledford, 2016).

allows very specific gene editing by snipping target DNA and limiting "off target" impact. Addgene, a nonprofit supplier of scientific reagents, has shipped tens of thousands of CRISPR toolkits to researchers in more than 80 countries, and there are now thousands of CRISPR-related publications in the scientific literature (Ledford, 2016).

CRISPR gene editing, DNA sequencing, big data and artificial intelligence are making possible a new era of personalized medicine. The large amounts of data gathered are "enabling scientists to identify key genetic predispositions to more than 5,000 of the inherited diseases resulting from mutations in a protein-encoding gene" and to target therapies based on the signatures of different mutations (Wadhwa with Salkever, 2017:126–127). Genome editing also allows disease-resistant genes from related wild plant species to be inserted in modern plants, and newly formed companies are using synthetic biology to develop biological nitrogen fixation to increase yields for African smallholders sustainably, by allowing crops to "fix" nitrogen from soil bacteria, reducing reliance on synthetic fertilizers.[19] Other companies are leveraging synthetic biology to make food flavourings (e.g. vanilla) that minimize oil inputs while mimicking the flavour of the natural product.[20]

## 4. Advanced materials and nanotechnology

Nanomaterials are materials manufactured and used at an infinitesimal scale, on the order of one billionth of a metre, which behave differently from their larger counterparts, for example in terms

[19] Engineering Nitrogen Symbiosis for Africa, available at www.ensa.ac.uk/.

[20] Evolval, available at www.evolva.com; Leproust (2015).

**Box 1.12 The potential of synthetic biology (CRISPR-Cas9)**

CRISPR originated from a bacterial immune system that conferred resistance to foreign genetic elements such as those from viral infections. More recently, it has emerged as a powerful tool for targeted genome modification in virtually any species, allowing scientists to make changes in the DNA in cells with the potential to prevent genetic diseases in animals or to develop new traits in plants.

CRISPR differs from conventional genetic engineering techniques in allowing the modification of targets or specific regions and sequences in the genome. Because it can modify a specific gene of interest, the technology is also called gene-editing. It works through a protein called Cas9, which is bound to an RNA molecule to form a complex. (RNA is a chemical related to DNA that allows interaction with DNA molecules with a matching sequence.) The complex functions as a sentinel in the cell, searching through the entire DNA to find matches with the sequences in the bound RNA and allowing the DNA to be cut at that site. Its success is largely due to its ability to be easily programmed to target different sites.

While CRISPR has the potential to operate as a stand-alone technology, its application in plants still relies on other genetic engineering tools (e.g. recombinant DNA, biolistic electroporation). It has been tested as a means of increasing yields and drought tolerance of commercial crops, improving their growth in low-nutrient environments, improving their nutritional properties and combatting plant pathogens. CRISPR-based genome engineering can also help to accelerate trait improvement in crops through conventional breeding approaches.

The possibility of genome editing requires consideration of various safety and ethical issues. Safety concerns include the possibility of generating permanent DNA breaks at unintended sites in the genome, as the off-target effects of CRISPR are only now beginning to be understood in more detail. The minor modifications arising from the use of CRISPR to edit small parts of DNA sequences also make it more difficult for regulators and farmers to identify modified organisms once they have been released, raising concerns about risk-monitoring, labelling and consumer rights.

The commercial and socio-economic implications of CRISPR gene-editing are likely to be similar to those of conventional genetic modification. The products of gene-editing are bound to be protected by intellectual property rights, with implications for the market power of seed and biotech companies as suppliers, and the purchasing power of farmers.[21]

*Source:* Sarah Agapito-Tenfen, GenØk Center for Biosafety, Tromsø, Norway.

[21] The intellectual property implications of synthetic biology are not clear. Initiatives such as iGem have created a Registry of Standard Biological Parts, making 20,000 documented genetic parts available for building synthetic biology devices and systems (see: igem.org/Registry). At the same time, given that no foreign genes are inserted into genetically edited crops, it may have implications for regulatory processes involving biotech crops.

of resistance, conductivity or chemical reactivity. They encompass a wide range of organic and inorganic materials, including nanocrystals and nanocomposites.

Nanotechnology is a general-purpose technology with multiple applications, which has the potential to revolutionize many industrial sectors. Its applications include:

(a) Water remediation and purification, for example through nanofiltration membranes used to treat wastewater in water-scarce countries;

(b) Increasing the heat resistance of materials and the flexibility and performance of electrodes in lithium-ion batteries;

(c) Precise control of the release of agrochemicals, improving seed germination and reducing toxicity in the agriculture process, increasing agricultural yields and reducing environmental impacts;

(d) Nanoelectronics include devices and materials that reduce weight and power consumption of electronic devices, for example the production of small electronic circuits, enhanced memory storage and faster computer processors; and

(e) Medical applications such as the use of gold nanoparticles in the detection of targeted sequences of nucleic acids, and of nanoparticles as a delivery mechanism for medications.

Nanotechnology is also being used to improve the preservation of agricultural produce in food security projects, such as the programme supported by the Canadian International Food Security Research Fund and the International Development Research Centre to enhance the preservation of fruits in India, Kenya, Sri Lanka, Trinidad and Tobago, and the United Republic of Tanzania.[22] A key part of the project involves hexanal (infused within a nanoparticle), an affordable and naturally occurring compound produced by all plants to slow the ripening of soft fruits and extend their storage life, as a spray (increasing retention time by up to two weeks for mangoes and five to seven days for peaches and nectarines), and to impregnate packaging to keep fruit fresh. Various technology-transfer mechanisms are used, including workshops, field days, seminars and public–private model centres.

## 5. Renewable energy technologies

Using smart grids, big data and IoT technologies can help to reduce energy consumption, balance energy demand and supply, and ensure and improve the management of energy distribution, while increasing the role of renewable sources by allowing households to feed surplus energy from solar panels or wind turbines into the grid. The real-time information provided by smart grids helps utility companies to respond better to changes in demand, power supply, costs and emissions, and to avert major power outages (UNCTAD, 2015d:23). Zenatix, a Delhi-based start-up, for example, uses smart meters and temperature sensors to help households and offices reduce energy consumption through message-based alerts, saving Indraprastha Institute of Information Technology nearly $30,000 annually.[23]

Renewable energy technologies can provide electricity in remote and isolated rural areas inaccessible to centralized grid systems (UNCTAD, 2017c); and costs have declined dramatically, especially for solar power, which is now cost-competitive with coal and natural gas. The cost of solar cells has dropped by a factor of more than 100 in the last 40 years, from $76.67/watt in 1977 to $0.029/kilowatt-hour (kWh) in 2017 (Clark, 2017). Solar energy is now the cheapest generation technology in many parts of the world.[24]

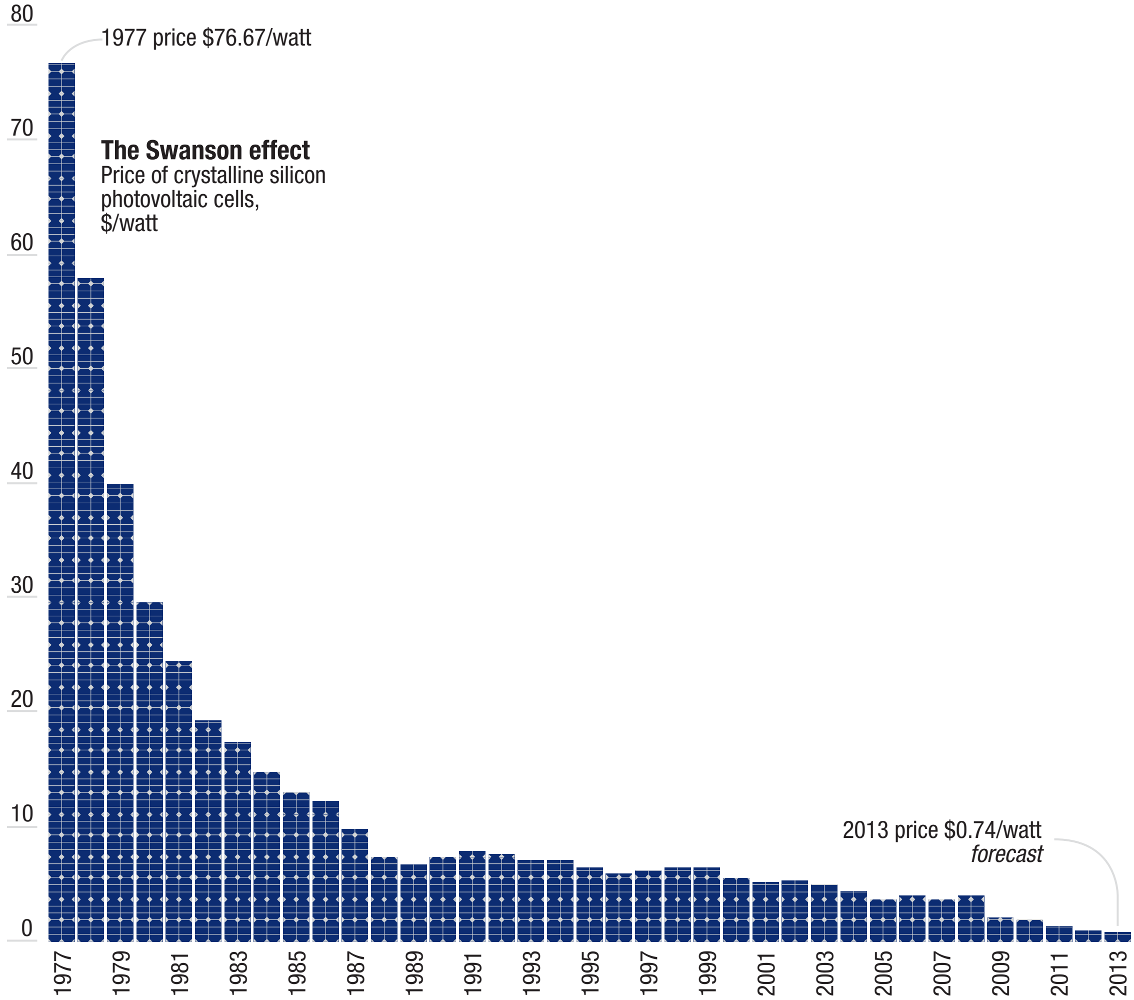
There is also progress regarding innovation in material science to produce third-generation solar PV. Although silicon-based solar PV is likely to remain dominant in the shorter term, a promising variety of third-generation thin film cells based on abundant materials (including copper zinc tin sulfide, perovskite solar cells, nanomaterials such as organic solar PVs, and quantum dot solar cells) is emerging. One of the most promising of these are perovskites solar cells, which have excellent light-absorbing capacities and lower manufacturing costs, with photoelectric efficiencies advancing from 10 to over 20 per cent between

[22] Contribution from the Government of Canada and Sri Lanka. More information is available at www.theepochtimes.com/n3/1835789-canadian-innovations-showcased-at-un/; www.abc.net.au/news/2015-03-17/nanotechnology-mangoes-india-srilanka-canada/6325346; and www.cbc.ca/news/canada/kitchener-waterloo/guelph-fruit-spray-extends-shelf-life-1.3647271 (all three sites accessed 15 March 2018).

[23] Dora, 2015b.

[24] See Jason Dorrier's interview with Ramez Naam, "Solar Is Now the Cheapest Energy There Is in the Sunniest Parts of the World," Singularity Hub, 18 May 2017, available at https://singularityhub.com/2017/05/18/solar-is-now-the-cheapest-energy-there-is-in-the-sunniest-parts-of-the-world/?utm_content=buffercf0fa&utm_medium=social&utm_source=facebook-su&utm_campaign=buffer (accessed 15 March 2018).

**Figure 1.4 Declining costs of solar cells**




2012 and 2015. However, perovskites are still in early stages of R&D, with uncertainty regarding long-term stability and feasibility for large-scale deployment (MIT Energy Initiative, 2015). Third-generation solar PV cells are aiming for combinations of high power conversion efficiency, lower cost and usage of materials, and lower manufacturing complexity and cost. Achieving all three remains elusive, but with more efforts into research and development, solar PV can achieve even greater scale of deployment.

The costs of batteries are also falling dramatically, mainly driven by the need for continuous energy supply from intermittent renewable technologies, while efficiency has increased (*The Economist*, 2017a). The cost of lithium-ion batteries per kWh has fallen by 80 per cent since 2008, from $1,000 to $200 per kWh, and are expected to fall further. Energy density has also increased, allowing more storage per kilogram, while durability has improved.

Rapid declines can also be observed in the cost of electric vehicles, fuelling a growing expectation that they will soon compete with conventional cars, in part because of deliberate policies in some countries. Scotland is aiming to phase out gasoline and diesel cars by 2032, and China, France and the remainder of the United Kingdom by 2040, while India is committed to selling only electric vehicles by 2032. The rapid development of electric cars has contributed to the improvements and cost reductions for battery technology (Clark, 2017).

## 6. Satellites and drones

Communication satellites have been used for Internet access in rural areas and developing countries since the early days of the Internet, and the industry has remained viable as a result of technical progress in launch technology (public and private), antennas, solar power, radios and other electronics, as well as tuning of TCP/IP protocols to account for the quarter-second latency due to the orbital altitude. It has been suggested that these technologies have progressed to the point where high-altitude platform stations (HAPSs) and lower orbit satellites are now viable as well. HAPSs are non-rigid airships, drones or balloons that hover or circulate around 15–30 km in the stratosphere (UNCTAD, 2014a). HAPSs have lower transmission delay (latency), but their signal cover (footprint) tends to be lower compared to other technologies (ibid.:38). An example of a project that offers broadband Internet using satellite communications is the Google Project Loon (ibid.), which uses HAPSs to create an aerial wireless network with up to 3G-like speeds.

In the future, everyone on Earth may have ubiquitous access to outer space (Buscher and Brieß, 2014). Exponential technologies have also made possible development of small, cheap and capable satellites, including "cubesats" – 10-centimetre cubes with various sensors, using smartphone technology – hundreds of which have been deployed. Microbes in Space and NanoRacks have partnered to produce cubesats on demand on the International Space Station: the design for a satellite can be emailed to a printer on the International Space Station, where the key components will be stored, allowing the case to be manufactured and the satellite assembled and deployed directly into orbit (Garrett, 2016). Custom cubesats will cost around $100,000, allowing them to be deployed by developing countries, businesses and universities, for example, for monitoring of crops or environmental damage or for surveillance.

Like robots, drones have existed for decades, but their cost and size have shrunk dramatically in recent years, powered by Moore's Law, while their capabilities have increased with smartphone technology. Small quadcopter drones are now being employed for an increasing number of tasks, including commercial delivery of packages and delivery of high-value items such as vaccines to rural areas in developing countries (Kolodney, 2017; d'Onfro, 2014). Hundreds of delivery drone companies are starting up all over the world, and 4.3 million drones were reportedly shipped in 2015, representing market growth of 167 per cent (Wadhwa with Salkever, 2017:113).

The decreasing cost of drones could also facilitate a wide range of services in developing countries, including delivering supplies to conflict areas, refugee camps and rural areas with poor ground transportation networks. Drone delivery in cities could significantly reduce congestion and pollution by reducing the use of delivery trucks, while drones can also perform hazardous jobs such as inspecting bridges, cell phone towers and roofs, and fire-spotting in rural areas, as well as providing new and cheap capabilities for precision agriculture, including monitoring the growth of weeds and crops, spraying insecticides and monitoring soil hydration.

## 7. Blockchain

A blockchain is a form of exchange that is permanent and transparent between parties, which does not rely on a central authority (Mulligan, 2017). The premise of the exchange is that each party on a blockchain has access and means to verify the entire database. Further, all transactions are visibly recorded across a distributed peer-to-peer network (Mainelli, 2017). Applications include the following:

(a) "Smart contracts"[25] are a form of a trusted third party which can automate transactions such as licencing, revenue collection and social transfers, significantly lowering costs.

(b) They provide recognized identification for the approximately 1.5 billion people who lack it, which would otherwise leave them vulnerable to legal, political, social and economic exclusion.[26] Blockchain has been used in identity management, which aids in validating individual identities. For example, Estonia offers citizens a digital identity card based on blockchain, which allows citizens to access public, financial and social services, as well as pay taxes.[27]

(c) Blockchain is increasingly being used in land and property registration, to validate government-related property transactions, reduce paperwork

[25] Smart contracts can automatically pay out entitlements when certain eligibility criteria are met and verified by the blockchain network.

[26] See ID 2020 Summit 2017, available at http://id2020summit.org/.

[27] Krishna et al., 2017.

and potentially to reduce property fraud. Examples of countries that are using blockchain for land registration are Ghana,[28] Georgia and Sweden.[29]

(d) Blockchain has been piloted with WFP[30] through a humanitarian aid project of cash and food assistance transactions in Jordanian and Syrian refugee camps. The aims are to reduce overhead, improve security and speed up aid in remote areas.

(e) In trade finance, which is characterized by many stakeholders and largely paper-based documentation, blockchain can simplify processes, reduce settlement times, errors, fraud and disputes, and increase trust between all parties to a transaction. A group of banks has partnered with blockchain service provider IBM on implementing a new blockchain-based global system for trade finance. Similarly, IBM has teamed with another set of banks to build and host a new blockchain-based system for providing SMEs with trade finance.[31]

## E. KEY CONSIDERATIONS FOR HARNESSING FRONTIER TECHNOLOGIES FOR SUSTAINABLE DEVELOPMENT

### 1. Artificial intelligence could create – and destroy – jobs

While frontier technologies can be expected to create new markets and jobs, they will also disrupt existing productive sectors and labour markets, with impacts that may particularly affect disadvantaged communities. The relationship between technology and employment has historically been controversial. At least in theory, the main objectives of technological progress are productivity growth leading to economic growth, and improved living standards. But technologies have often been seen as a major contributor to unemployment and inequality. For example, the Luddite movement in the United Kingdom emerged in response to the First Industrial Revolution, to protest against the use of machines that were destroying jobs in the textile industry. The debate about the impact of technology on employment has been reignited recently, particularly in developed countries, by increasing inequality, high rates of unemployment, the rapid advance of artificial intelligence and robotics, and increasing digital automation of production processes – the so-called Fourth Industrial Revolution.

The rapid pace and widening scope of technological progress could lead to more job destruction than job creation, at least in the short and medium term. A polarization of employment has been observed as jobs at medium skill levels have declined, while non-routine jobs, both manual (low-skilled) and cognitive (high-skilled) have increased (UNCTAD, 2016b). While digital automation allows some countries and businesses to produce goods and services at unprecedented scale, increasing labour productivity and expanding operations at marginal cost, this may eliminate the need for workers. Recent advances in automation thus have the potential to affect a radical reshaping of work.

#### a. *Differing perspectives on the potential impact of automation on employment*

Numerous recent studies have considered the impact of automation and robotics on employment. The more pessimistic side of the debate considers that, contrary to previous historical experiences, robots may replace workers faster than the labour market and policies can adapt, resulting in a negative net impact on employment. Studies taking this view focus on the many jobs that are at risk of automation through the rapid pace of digital automation, which could result in increasing productivity not being matched by higher wages and job growth (Frey and Osborne, 2013; World Economic Forum (WEF), 2016a and 2016b; Brynjolfsson and McAfee, 2014; Pew Research Center, 2014). Some such studies also highlight the gender implications of automation and employment (box 1.13).

There are three reasons to consider that the relatively favourable long-term labour market outcomes of past technological shocks may not be replicated in the current circumstances, or at least that the job losses during the transition may be higher and take longer to absorb. First, recent and prospective technological changes are occurring much more rapidly and within a much shorter time frame than agricultural mechanization, the Industrial Revolution and mechanization of manufacturing. This requires

[28] E.g. the ongoing work of Bitland in Ghana, or Bitfury in Georgia. See Financial Times, 2017a.

[29] See *The Economist*, 2017b.

[30] WFP, Building blocks. Available at http://innovation.wfp.org/project/building-blocks.

[31] See *Financial Times*, 2017b.

much faster adaptation, and increases the likelihood of a medium-term hiatus between negative short-term effects on employment and potential off-setting effects in the long term. The current pace of technological change, together with its unpredictability, also raises concerns about the viability of retraining: skills may be useful only for a relatively short time, reducing returns relative to the costs, particularly given the time required for training itself.

Second, past technological changes have created a certain amount of employment with limited skill requirements in the affected sectors because new technologies (tractors and farm machinery in the agricultural revolution, and increasingly mechanized factories) required human operators with moderate skill levels. The advent of artificial intelligence and autonomous machines means that, in many cases, the need for human agency is averted (or limited to users, in the case of services). This implies that employment opportunities will be both more limited and confined largely to much higher-skilled tasks, often in different locations, for the design, manufacture, maintenance and repayment of the new equipment.

Third, previous episodes of technological change have mainly affected a single (broadly defined) sector. Workers displaced by agricultural mechanisation could move into pre-industrial manufacturing and services, and later move to urban areas, providing the workforce for the Industrial Revolution. As employment was reduced by increasing mechanization in industry, workers could move into services. By contrast, the revolutionary nature of current and prospective technological changes means that all sectors will be affected simultaneously. Moreover, employment effects are likely to be particularly strong in major services such as wholesale and retail trade, retail financial services and transportation, which have previously played an important role in absorbing labour displaced from agriculture and industry.

More optimistic studies consider that the negative short-term effects will be offset in the long term by higher productivity and the creation of new jobs involving more creative and interesting tasks – those requiring personal interaction, social skills, negotiation skills, empathy and emotional intelligence, human touch and ability, common sense, persuasion, intuition, judgment and problem-solving skills. Such skills cannot readily be codified and quantified, while robots cannot readily mimic the dexterity and flexibility of human motion. Robots are thus seen as complementary to human work (Arntz et al., 2016; Organization for Economic Cooperation and Development (OECD), 2016; McKinsey Global Institute, 2017; Bessen, 2016; Autor DH, 2015; Executive Office of the President of the United States, 2016; Stewart, et al., 2015).

**Box 1.13 Potential gender implications of digital automation**

Digital automation can affect women and men differently. Analyses on the impact of automation by gender are equally scarce. According to WEF (2016b:5): “From a net employment outlook perspective, expected absolute job creation and losses due to disruptive change over the 2015–2020 period are likely to amplify current gender gap dynamics.” This is because a large share of women tend to be employed mostly in routine and lower-skills occupations which present the highest risk of automation. These women’s job losses resulting from automation could be particularly important in developing countries, where export processing, exports on non-traditional agricultural products and exports of services such as data entry and call centres have led to increased hiring of women, who receive lower wages and have lower skills (UNCTAD, 2016c). On the winners’ side, as women constitute low numbers in the science, technology, engineering and mathematics job families, and therefore they may not be able to take advantage of the increased demand for workers with skills in these areas, most of this job creation is likely to benefit men. Similarly, a study of the United States economy (Cornerstone Capital Group, 2016) concludes that women face greater risk of job losses as a result of computerization. Jobs at “lower risk”, which are typically dominated by women, pay less than low-risk male-dominated jobs. Women hold nearly 60 per cent of jobs facing very high risk of computerization. At the regional level, the International Labour Organization (ILO) (2016) found that in all of the ASEAN-5 women are more likely than men to be employed in an occupation at high-risk of automation. The situation was worst for women in the Philippines and Viet Nam, where they are between 2.3 and 2.4 times more likely than men to be in a job at high-risk of automation. The difference is smaller in Indonesia, Thailand and Cambodia, but even in those countries women are between 60 and 20 per cent more likely than men to be in occupations at high risk of automation. Thus, automation may hamper the attainment of Sustainable Development Goal 5 (gender equality).

*Source:* UNCTAD secretariat.

### *b. The impact of automation on employment in developing countries*

The impacts of automation vary according to levels of development and industrialization, labour costs, skills capacities, production and export structures, and related factors such as technological capacities, infrastructure, demography and policies that encourage or discourage automation (box 1.14). However, most analyses of the social and employment impact of digital automation to date have focused primarily on developed countries, reflecting their proximity to the technological frontier, the greater profitability of automating processes where labour costs are higher, and the presence of large companies and factories with the advanced technologies needed to produce higher-end robots (Boston Consulting Group, 2015:6; National Bank of Canada, 2013).

**Box 1.14 The great convergence – The changing geography of manufacturing and knowledge**

According to Baldwin (2016), while the “Old Globalization” that started in the early 1800s lowered costs of moving goods, the New Globalization of the late twentieth century reduced the cost of moving ideas. “Old Globalization” concentrated wealth in the hands of today’s rich nations, often referred to as the “Great Divergence”. However, since the 1990s, the “Great Convergence” has been reversing the gains of those rich nations.

The share of manufacturing has radically shifted since the 1990s, in what Baldwin calls the “shocking share shift”, where the Group of Seven’s rapid loss has been accompanied by massive growth in the share of the Industrializing Six, or I6 (China, Republic of Korea, India, Poland, Indonesia and Thailand). He argues that globalization unbundles the “forcible bundling” of production with consumption. Globalization reduces the “separation” costs of production and consumption through three dimensions of distance-related costs: moving goods, moving ideas and moving people. These constraints, and the sequence by which these constraints are ameliorated, explain how globalization has and is evolving.

In the first wave of globalization, or the “first unbundling”, the costs of moving goods fell and expanded markets. However, industry clustered in the North and, with the high costs of moving ideas, much know-how remained in the North, leading to the innovation-based growth that has defined the North–South income differences. The second wave of globalization (or the “second unbundling”) involved a reduction in the cost of moving ideas. Lower-cost communications enabled the offshoring of production and international production networks, which not only created jobs in developing countries but diffused knowledge (e.g. “marketing, managerial and technical know-how”). What distinguishes this New Globalization is the combination of low-wage labour from the South with know-how from the North. Baldwin argues that the diffusion of knowledge to these regions, along with jobs, was necessary to construct well-functional global production networks. This allowed knowledge only previously held within Group of Seven firms to be diffused to other locations.

However, knowledge flows to developing countries were concentrated, in part, because of the continued high costs of moving people. Most offshore locations are near “G7 industrial powerhouses” or where face-to-face interaction is not as salient. Baldwin argues that because half of humanity lives in these industrializing developing countries, income growth has driven a “commodity super-cycle”, impacting other commodity-exporting nations (even those untouched by global value chains).

Baldwin hypothesizes that a “third unbundling” could occur if the costs of moving people are reduced, either through “telepresence” technologies or “telerobotics” that allow people to perform tasks in remote locations. Such “virtual immigration” or “international telecommuting” would enable workers to perform services in other nations without physical presence.

*Source:* Baldwin (2016).

There are two main channels through which automation may affect employment in developing countries. First, ***increasing automation in developed countries*** may erode the comparative advantage of developing countries, which is based largely on abundant low-cost and low-skilled labour. Increasing use of robots in developed countries may slow the offshoring of activities by transnational companies, although labour cost differences (relative to robots) remain a factor in such decisions. If robots in the home country of a company that has offshored its activities can do the same work as low-wage workers in developing countries at lower cost, such activities may also be reshored to the home country, leading to job losses. While there has already been some reshoring of manufacturing activities linked to automation, the evidence of its importance is limited and mixed (UNCTAD, 2016b;

De Backer et al., 2016). Reshoring linked to automation is unlikely to increase employment in developed countries significantly, as robots may perform most of the previously offshored tasks, so that jobs created may be a fraction of those lost through past offshoring.

Second, employment may be affected by the ***automation of industrial production processes in developing countries themselves***. This reduces the potential of the manufacturing sector to absorb large domestic labour surpluses from the primary sector, and adds to existing stresses on labour markets associated with relatively high population growth. It may also weaken developing countries' traditional comparative advantage in low-cost and low-skill labour by making production less labour-intensive, again contributing to a reversal of the offshoring of labour-intensive manufacturing activities from developed to developing countries. Overall, automation in developing countries may imply some net job destruction by limiting their ability to create new jobs through manufacturing, contributing to premature deindustrialization (Rodrik, 2015; Frey, 2015).

The ability of countries to take advantage of an increasingly automated world has become a key determinant of competitiveness (UNCTAD, 2017b). The role of manufacturing is particularly important in this regard, as a share of manufacturing in employment of at least 18 per cent has been identified as a good predictor of eventual prosperity (UNCTAD, 2017a). In principle, the maturing of structural transformation in more advanced developing countries is shifting employment towards services, facilitating the transitions of other developing countries. However, increasing automation in manufacturing raises important questions about the future feasibility of such transitions.

The impact of automation is likely to depend less on its technological feasibility than on its economic feasibility; and adverse employment effects may be greater in economies that do not use robots than in those that do (ibid.). This suggests that fears about short-term adverse effects of digitalization and automation on employment may be exaggerated, particularly if labour and education policies promote complementarity between skills available in the workforce and new technologies.

The critical issue is the need for technical feasibility to be matched by economic profitability. While automation has developed rapidly, market selection will likely dictate the most economic sense. Since the impact of automation on industrialization depends on the structure of each country's economy (ibid.), the impact at the national level cannot be assumed to be necessarily negative, but rather requires a balanced analysis of the net effects of technological and market forces. Thus, the future lies in workers creating economic value with machines rather than against them (UNCTAD 2017b).

In the longer term, automation should give rise to new opportunities for job creation in those middle-income countries with sufficient technological and absorptive capacities, the skills and technological infrastructure needed to make robots work and maintain them, and the capacity to upgrade skills according to the new occupations created. China and the Republic of Korea provide examples of possible trajectories for such countries. However, if robots are imported, job creation effects linked to their production will accrue in the producing countries.

In the LDCs, where the creation of jobs for a large pool of low-skilled new entrants to the labour force is a major priority, the introduction of robots is unlikely to be economical. LDCs' production structures are typically dominated by small-scale agriculture and large informal sectors. There are major gaps in technological and absorptive capacities and technological infrastructure, and serious shortages of high-skill workers. Also, declining costs of automation do not compensate for low wage levels.

While automation in LDCs might in principle be possible by leapfrogging (chapter IV), as many have done by adopting mobile telephones before developing fixed telephoned lines, this would require the cost of automation costs to fall below that of the cheapest labour. Moreover, as noted by ILO (2015:4), these technologies will make it increasingly difficult for African countries to leapfrog into cutting-edge manufacturing technologies unless they rapidly develop a highly skilled labour force with the capabilities to implement and operate highly automated production processes. As in many developing countries, the fact that most technology in LDCs is imported, mainly from developed countries, will limit any job creation effect domestically.

**Box 1.15 Studies on the impact of automation on employment in developing countries**

Studies about the impact of automation on employment in developing countries are rather scarce. According to the World Bank (2016), the proportion of jobs at risk of automation is even higher in developing countries than in developed countries: from a purely technological standpoint, two thirds of jobs in developing countries are susceptible to automation in coming decades. However, the effects of that process could be moderated by the lower wages and the slower adoption of technology in developing countries. Therefore, although given the technological advances the potential for automation is clear, this should not be considered as a concern in the short term for a number of reasons: first, there will be creation of new jobs and new tasks in existing occupations; second, robots are not perfect or even good substitutes for many tasks. Moreover, automation is likely to be slower and less widespread in developing countries as a result of barriers to technology adoption, lower wages and the higher presence of jobs based on manual dexterity. As the labour disruptions from automation are expected to arrive more slowly to the poorest countries, this may give more time for policies and institutions to adapt.

According to estimates by the World Bank (2016:figure 2.24), using an unadjusted measure (based on technological feasibility), the share of employment that is susceptible to automation by country ranges from 55 per cent in Uzbekistan to 85 per cent in Ethiopia. Other countries in which this share is close to 80 per cent are Nepal, Cambodia, China, Bangladesh, Guatemala and El Salvador. When the numbers are adjusted by the adoption of time lags, the shares are much lower, ranging from 34 per cent in Uzbekistan to 65 per cent in Argentina. The share in Ethiopia goes down from 85 per cent to 44 per cent. In the OECD, an average of 57 per cent of the jobs could be automated.

Working with the data of the World Bank, Citi GPS and Oxford Martin School (2016) conclude that "jobs in developing countries are also susceptible to automation. Due to technological advancement, low-wage regions which have traditionally attracted manufacturing firms will not have the same possibility of achieving rapid growth by shifting workers from farms to higher-paying factory jobs – therefore, they would need to find a different path to prosperity." They also show that countries with a higher share of their workforce at risk of automation tend to be those with lower levels of gross domestic product (GDP) per capita.

In a study of 46 countries, McKinsey Global Institute (2017) shows that automation has the potential to affect activities associated with 40 to 55 per cent of global wages. There are variations depending on the country, based on a number of factors, such as the level of wages and the cost of deploying solutions. There is a high concentration, as more than half the wages and close to two thirds of the total number of workers associated with technically automatable activities are in China, India, Japan and the United States. This study finds that "Almost half of work activities globally have the potential to be automated using current technology. <5 per cent of occupations can be automated entirely; about 60 per cent have at least 30 per cent of automatable activities" (ibid.:21).

At the regional level, a study by ILO (2016) for the Association of Southeast Asian Nations (ASEAN) 5 (Cambodia, Indonesia, the Philippines, Thailand and Viet Nam), found around 56 per cent of all employment is at high risk of automation in the next few decades. The share of jobs with a high probability of automation is lowest in Thailand (44 per cent) and highest in Viet Nam (70 per cent). In the Philippines, Indonesia and Cambodia, the shares are 49 per cent, 56 per cent and 57 per cent, respectively. Considering the percentage of workers at high risk of automation by key sectors, the highest share is found in business process outsourcing/call centres in the Philippines (89 per cent), followed by garments in Cambodia and Viet Nam (88 and 86 per cent, respectively), the share of retail in Indonesia (85 per cent) and the lowest share is that of motor vehicles in Thailand (73 per cent).

Looking in particular at automation in the services sector, HfS Research (2016) estimates that by 2021 total jobs will fall by 9 per cent and low-skilled jobs by 30 per cent, while medium-skilled jobs will increase by 8 per cent and high-skilled jobs by 56 per cent. The highest impact is to be found in low-skilled United States and Indian services workforces. The Philippines, United Kingdom and India are set to benefit the most from medium- and high-skills job creation.

*Source:* UNCTAD secretariat.

## 2. Frontier technologies present challenges for privacy, security and algorithmic transparency

Despite their potential benefits, frontier technologies also give rise to potential risks, and pose important ethical questions, that should be considered and appropriately managed. Digital technologies for instance can pose new challenges to citizens' rights and the power balance between stakeholders related to the ownership of data. The increasing availability of data associated with big data applications and IoT devices, and the increasing accessibility of personal data to commercial and government entities, raise important issues of privacy and security, reinforcing the need for regulation of data sharing and use. The report of the United Nations High Commissioner for Human Rights, the Right to privacy in the digital age,[32] warns of "a lack of adequate national legislation and/or enforcement, weak procedural safeguards, and ineffective oversight" with respect to the right to privacy (UNCTAD, 2015e:30). Particular issues are individual notice and consent, opt-out policies and anonymization (Mayer-Schönberger and Cukier, 2013:6).

Big data allows the use of digital automation algorithms, for example, by financial institutions to make decisions on credit applications, by Internet companies to decide which advertisements to show users, and by retailers to decide which discounts or deals to show potential and repeat customers. Such algorithms are not infallible, and errors can arise from communications or sensor failures, unforeseen data volumes, incorrect computer code, or computer or data-storage failures.[33] They also need to be better understood, to identify and mitigate potential discriminatory biases.

Consideration is therefore needed of appropriate regulatory frameworks for data collection, usage and access, to safeguard privacy and security, while balancing individual and collective rights (including freedom of expression and information), and allowing private sector innovation. Governments can also create and support new institutional mechanisms for monitoring data sharing and use, and work with local companies to promote practices for safeguarding privacy and security that are compatible with national regulation. Institutional arrangements may also be appropriate for monitoring and transparency of digital automation algorithms and to evaluate the societal implications of their applications, given their power to shape the experiences of individuals.

Governments can also play a role in developing standards for the interoperability of big data and data from IoT devices (Manyika et al., 2015a). There is also a need to promote greater awareness of cybercrime and to develop cybersecurity policies and strategies, for example, to safeguard against illegal sharing of data for 3D printing and unauthorized use of private or confidential data from web applications, eLearning and massive open online course platforms, mobile phones and IoT devices.

## 3. Frontier technologies have an unclear relationship to productivity growth and other development indicators

The potential of frontier technologies may not be diffused to all firms and sectors, and consequently may not be fully reflected in key aspects of sustainable development, particularly productivity. Expert opinion is broadly divided between three views:

(a) That there has been a secular decline in productivity due to declining innovation, and that this is likely to continue, negatively affecting employment growth;

(b) That productivity is near historic highs in those advanced industries that utilize technological advances, while industries and firms that fail to do so are lagging far behind; and

(c) That current criteria for measuring productivity are deeply flawed and fail to reflect productivity growth in full.

Some influential economists maintain that the impact on productivity of "narrow" technological breakthroughs in the last decade has been much more limited than that of the inventions of the late nineteenth century (Gordon, 2016). Productivity growth has slowed since 1970, with an uptick between 1994 and 2004. The major period of productivity growth was 1920–1970, when output per hour rose at nearly 3 per cent per year, reflecting technological innovations after 1870, including (a) the energy revolution associated with the exploitation of oil, the harnessing of electricity and the development of the internal combustion engine; (b) the birth of the chemical industry; and

32 Available at: www.ohchr.org/EN/HRBodies/HRC/RegularSessions/Session27/Documents/A.HRC.27.37_en.pdf (accessed 16 March 2018).

33 Atlantic Council FutureScape, 2013:7.

(c) transformative developments in water supply and sewage disposal (Wolf, 2016).[34]

Others argue that "frontier" firms within industries are much more productive than non-frontier firms, and that the minimal impact of new technologies on overall productivity growth reflects limited diffusion of rapid technological advances. In manufacturing, according to some estimates, advanced firms generate $216,000 of output per worker, compared with $102,000 for non-advanced firms (Muro, 2016). Recent OECD research finds that the top 100 global productive "frontier" firms across industries are on average 4 to 10 times more productive than non-frontier firms (Andrews et al., 2015:2).[35]

There is also a question as to whether current indicators measure productivity accurately in the era of the digital economy. It has been argued that the entire framework of productivity measurement may be flawed, and that official economic statistics may underestimate it by a wide margin (Karabell, 2017). For example, several decades ago, a long-distance domestic telephone call could cost $1.00 per minute and an international call $5.00 per minute, which was added to GDP, and thus contributed to measured productivity. Now, video calls are possible globally via free telecommunications application software, greatly enhancing business communications and productivity as well as improving lives. However, since these applications are free, they add nothing directly to GDP, or therefore to productivity as currently measured.

[34] Robert J. Samuelson cites a new study indicating the as much as a 1.2 per cent decline in GDP growth can be linked to ageing of United States society and probably in other countries as well. "Are ageing and the economic slowdown linked?" *Washington Post*, 21 August 2016, available from www.washingtonpost.com/opinions/are-aging-and-the-economic-slowdown-linked/2016/08/21/ffd6b270-6626-11e6-96c0-37533479f3f5_story.html?utm_term=.12a1c7f1a3da (accessed 16 March 2018).

[35] According to Andrews et al. (2015:2): "Despite the slowdown in aggregate productivity, productivity growth at the global frontier remained robust over the 2000s. At the same time, the rising productivity gap between the global frontier and other firms raises key questions about why seemingly non-rival technologies do not diffuse to all firms. The analysis reveals a highly uneven process of technological diffusion, which is consistent with a model whereby global frontier technologies only diffuse to laggards once they are adapted to country-specific circumstances by the most productive firms within each country (i.e. national frontier firms)."

## F. CONCLUSIONS: PROACTIVE POLICIES KEY TO HARNESSING FRONTIER TECHNOLOGIES FOR THE SUSTAINABLE DEVELOPMENT GOALS

One relative certainty is that the future will not simply be an extrapolation of the recent past. The world of 2025 and 2035 will be very different from the present, particularly because of the widespread deployment of frontier technologies. In the field of trade, as discussed in UNCTAD (2017b), the development of the digital economy is driving a global economic transformation that creates opportunities to cut costs, streamline supply chains and more easily market products and services worldwide. With adequate policy support, this could open opportunities for firms from developing countries. In agriculture, as noted above, drones, sensors, robotics, mobile and cloud computing, artificial intelligence and genomics could combine to bring large improvements to food security. Renewable energy and distributed energy systems have the potential to create local jobs, directly and indirectly, as well as widen electricity access, particularly in rural areas.

Crucial to the development of these frontier technologies is that connectivity, including broadband Internet access and mobile devices, are affordable and available. In addition, an enabling environment that includes business-friendly regulations, investing in modern energy and transport infrastructure, increasing availability of capital, including for innovative firms and SMEs, will be needed.

The global availability of frontier technologies at declining costs can enable entrepreneurs to create new companies and other organizations, and governments to apply these technologies and draw on a large and growing base of platform users. By 2025, nearly every person on the planet is expected to have access to the extraordinary capabilities of Internet-connected mobile devices, including free access to the GPS for geolocation, enhancing business prospects through its integration into commercial apps and websites. In the right environment, such technologies could enable developing countries to leapfrog stages of technological development (see chapter IV). In this regard, the use of smartphones offers important lessons: while very few people understand the workings of a smartphone, more than 2 billion people are able to use them for an amazing array of functions, many directly relevant to work, including geolocation, information access and retrieval, email and messaging, posting of economic and other business information on social media, ride-hailing and other ecommerce functions, translation, accessing thousands of servers for artificial intelligence-enabled functions, and many other tasks.

However, frontier technologies can also exacerbate existing economic, social and technological divides. Big data, IoT and other digital technologies could be harnessed by countries, regions and cities with strong existing capabilities, leaving others further behind. Much of the innovation in 3D printing, for example, emanates from countries that already have well-established manufacturing capabilities. Similarly, massive open online courses may enable better-off, more educated and more digitally-connected students and professionals to supplement their education with world-class content, leaving further behind those without digital access, economic opportunities or accessible education. As already noted, convergence multiplies the power of technology but may also result in a concentration of power in large market players, with potential negative impact on the empowerment of operators from developing countries. Some technologies may also carry risks of overexploitation of natural resources (for example, fisheries). Therefore, as discussed in the rest of the report, governments and other stakeholders need to be proactive in putting in place policies that minimize such socioeconomic or environmental risks, and ensure that the benefits of technologies are distributed equitably within and across countries.

Despite their considerable potential, frontier technologies alone will not address the challenges of sustainable development. History shows that the application of technology to sustainable development challenges requires resource mobilization, national capacities and policies, and regional and international cooperation. Nationally, there is a need to build local capacities and develop policies and an enabling environment to support the use of new and existing technologies for sustainable development. For example, with regard to digital technologies and as noted by UNCTAD (2017d), many countries still fail to address investment issues in their digital development plans. There is also a need to facilitate the adaptation of technologies to very varied local contexts and to ensure that they are deployed in a manner that responds to the needs and lifestyles of local communities. Globally, achieving the Sustainable Development Goals will require unprecedented resource mobilization, partnerships and multilateral collaboration to fund Sustainable Development Goal-relevant R&D, to build networks, to strengthen the global science–policy interface, to transfer technologies and to support the development of capabilities in developing countries.

Current national and international efforts are seriously inadequate to this task. The discovery, development, dissemination and absorption of useful technologies need to be scaled up and accelerated significantly, as does the application of STI policy to build STI capacities and improve innovation systems, to widen participation in the emerging Fourth Industrial Revolution and to spread the economic and social benefits of frontier technologies, leaving no one behind.

The remainder of this report will be organized as follows: Chapter II discusses the capacities that are needed to fully harness the benefits of STI for the Sustainable Development Goals. This is followed in chapter III by the consideration of the foundations of STI policy that need to be in place in order for technology, both frontier and more established technology, to be harnessed for inclusive and sustainable development. Chapter IV presents several new approaches to STI policy for development, some of which are facilitated by new forms of collaboration thanks to digital platforms, that present opportunities for countries to consider in their efforts to make frontier technologies effective means of implementation of the 2030 Agenda for Sustainable Development.

**Box 1.16 Key messages and conclusions**

(a) Business as usual will not be sufficient to harness frontier technologies for sustainable development and the Sustainable Development Goals.

(b) STI policy has a major role to play in meeting the Sustainable Development Goals. Frontier technologies offer great opportunities for the Sustainable Development Goals. In many fields relevant to the Sustainable Development Goals, they hold the promise to deliver better, cheaper, faster results in an easier and more scalable way. However, they also bring challenges and risks that need to be understood.

(c) The rapid proliferation of new technologies could overwhelm the capacity of policymakers and societies to adapt to them. Policymakers need to develop plans based on technology foresight and the assessment of technologies future effects. This could also involve increasing policy experimentation and facilitating shorter, more responsive innovation cycles.

(d) Governments may consider developing national big data strategies to harness big data for sustainable development.

(e) The net impact of rapid technological change on employment is still uncertain, although in the short term it could lead to more job destruction than creation.

(f) Frontier technologies pose questions related to privacy, security and the transparency of algorithms. Policymakers should consider the need for appropriate regulatory frameworks for data collection, usage and access, to safeguard privacy and security, while balancing individual and collective rights and allowing private sector innovation.

(g) We do not yet properly understand the relationship between frontier technologies, productivity growth and the implications on society. More research is needed to inform policy in this respect.

(h) Despite their considerable potential, frontier technologies alone will not suffice to address the challenges of sustainable development. Governments and other stakeholders need to be proactive in putting in place policies that minimize their risks and ensure the equitable distribution within and across countries of the benefits of technologies.

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## CHAPTER II

# BENEFITING FROM FRONTIER TECHNOLOGIES: GAPS AND CAPABILITIES

## A. INTRODUCTION

Developed and developing countries face the challenges and opportunities of sustainable development in the era of the Fourth Industrial Revolution presented in chapter I from very different starting points. Trends in frontier technologies, which are fundamentally enabled by the Internet and ICTs, are superimposed on a world with existing technological divides both between and within nations.

To address the overarching commitment of the 2030 Agenda for Sustainable Development to "leave no one behind", this chapter focuses on the key divides that could hinder countries in harnessing the benefits of frontier technologies. This is vital to understanding who is lagging how far behind and to identifying measures to mitigate such divisions. Responding adequately to such challenges will require capabilities.

This chapter considers the gaps in such capabilities, both to generate new technologies domestically and to absorb technologies produced in other countries and use them beneficially. In particular, it discusses:

(a) The divide in research and development (R&D) intensity and the uneven distribution of researchers, particularly in developing countries;

(b) The vast differences in science, technology, engineering and mathematics (STEM) education both between and within regions;

(c) The impact of technological advancement in manufacturing economic structural transformation;

(d) The need for reform of educational institutions to allow better preparation of present and future workers for digital skills;

(e) The significance of gender in the technological and digital divides; and

(f) The crucial relationship between energy access and Internet use.

## B. THE INTERNATIONAL DIVIDE IN RESEARCH AND DEVELOPMENT CAPABILITIES

**Sustainable Development Goals Target 9.5: Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending.**

Expenditure on R&D[36] as a proportion of GDP, also known as R&D intensity, is the most widely used indicator of countries' efforts on science, technology and innovation (STI). Increasing R&D intensity remains a long-term objective worldwide. In the European Union, for example, the Europe 2020 target for R&D is 3 per cent of GDP.[37] In 2014, only four European Union member countries (Finland, Sweden, Denmark and Austria) met this target (Eurostat, 2016). Similarly, African Governments have committed themselves, through the African Union, to invest at least 1 per cent of their GDP in R&D.[38]

Figure 2.1 shows the evolution of R&D intensity globally, by geographical region and in the least developed countries (LDCs). While it has increased significantly in some regions, R&D intensity in most developing countries is much lower than either the world average or that of developed countries in Europe and North America, which exceeds 2 per cent. The technological gap is particularly acute for LDCs, where intensity was only 0.25 per cent in 2014, and in sub-Saharan Africa, where it was 0.41 per cent.[39]

With the exception of middle-income countries, growth in R&D spending has been below that in developed countries (United Nations, 2017). Only three developing countries – the Republic of Korea (4.27 per cent), Singapore (2.20 per cent) and China (2.02 per cent) – reached R&D intensity above the world average in 2014.[40] The indications are that R&D expenditure and numbers of researchers closely follow economic trends. The poorest countries thus continue to lag far behind the most advanced countries.

[36] R&D comprises creative and systematic work undertaken to increase the stock of knowledge, including the knowledge of humankind, culture and society, and to devise new applications of available knowledge (OECD, 2015). It covers three types of activity: basic research, applied research and experimental development.

[37] Europe 2020 strategy, available at http://ec.europa.eu/info/strategy/european-semester/framework/europe-2020-strategy_en (accessed 21 March 2018).

[38] Science, Technology and Innovation Strategy for Africa 2024, available at www.au.int/web/sites/default/files/documents/29957-doc-stisa-published_book.pdf (accessed 21 March 2018).

[39] Throughout this section, definitions of country groups correspond to those of the source used.

[40] Data from UNESCO Institute of Statistics (UIS). Available at http://data.uis.unesco.org/ (accessed 21 March 2018).

R&D efforts may be performed and financed by enterprises, government or higher education institutions, among others. The objectives of public and private research differ widely. Public research generally has the objective of expanding the knowledge base and obtaining recognition for this, and does not necessarily result in upgrading of the technological capabilities of industrial sectors. Conversely, private research is motivated primarily by the practical application of the knowledge that it develops. Business R&D is therefore particularly relevant to such upgrading and to encouraging innovation, and thus to development.

In most developed countries, at least half of total R&D is performed by enterprises, reflecting their heavy involvement in formal innovative activities. In developing countries, by contrast, firms' involvement in formal innovation is mixed. While firms are heavily engaged in innovation activities in some developing countries – such as China, the Republic of Korea and Singapore – the share of business R&D to total R&D expenditure in developing regions is far below the world average of 65.9 per cent: 38.3 per cent in sub-Saharan Africa, 35.2 per cent in Asia–Pacific and 32.2 per cent in Latin America in 2011. The highest levels were registered in Japan, Hong Kong (China), Singapore, the Republic of Korea and Taiwan Province of China (75 per cent), China and India (69.7 per cent) and North America (67.6 per cent) (UNESCO, 2016).[41]

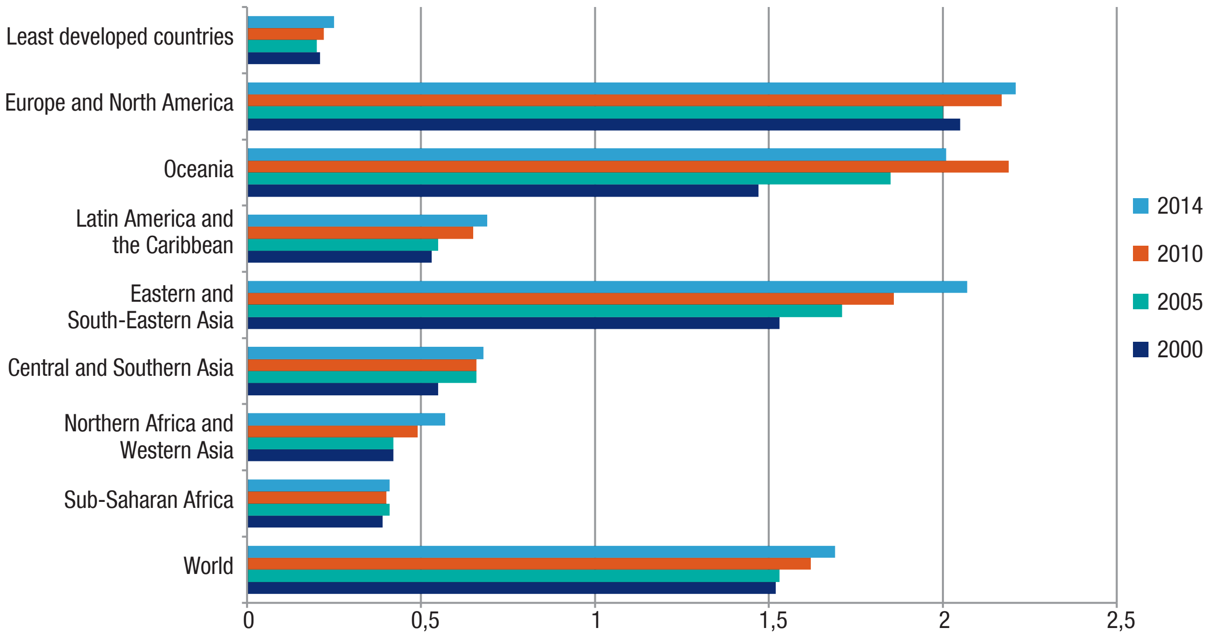
The density of researchers is also very unevenly distributed around the world, with Europe and North America leading, and significant growth since 2000 in all regions except LDCs, sub-Saharan Africa and Central and Southern Asia (figure 2.2). (United Nations Educational, Scientific and Cultural Organization (UNESCO), 2016). While there were 1,098 researchers per 1 million inhabitants in 2014 globally, the corresponding figures for LDCs and sub-Saharan Africa were 63.4 and 87.9 per 1 million, respectively.

A related indicator is the share of science, technology, engineering and mathematics (STEM) graduates in tertiary education.[42] Of the 20 million students awarded

[41] For more detailed data by country of R&D expenditure by source of funds and by sector of performance for 2014, see UNESCO–UIS (2017a).

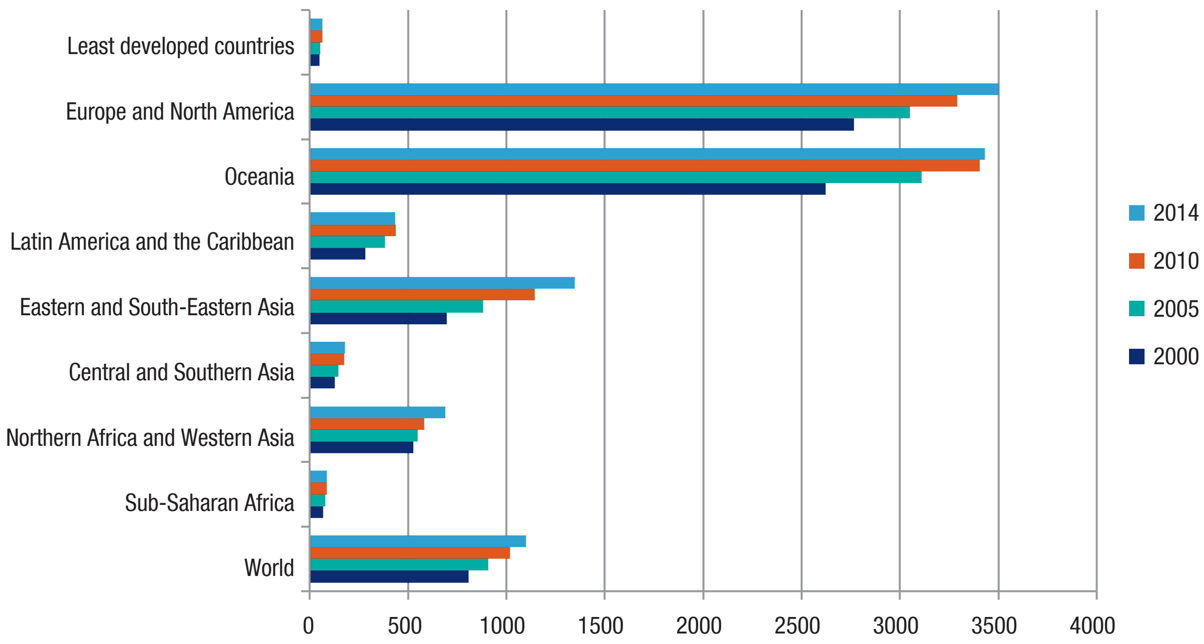
[42] International analyses and comparisons on STEM education are problematic because of inter-country variations in the definitions of STEM taxonomies, educational quality and levels of reporting. Most importantly, there is a significant scarcity of data, particularly for developing countries. The analysis presented here is based on a compilation made by the National Science Board of the United States (National Science Board, 2016), which defines STEM as including physical and biological sciences, mathematics/computer sciences, agricultural sciences and engineering.

**Figure 2.1 Research and development expenditure as a proportion of GDP, by region, 2000–2014 (Percentage)**



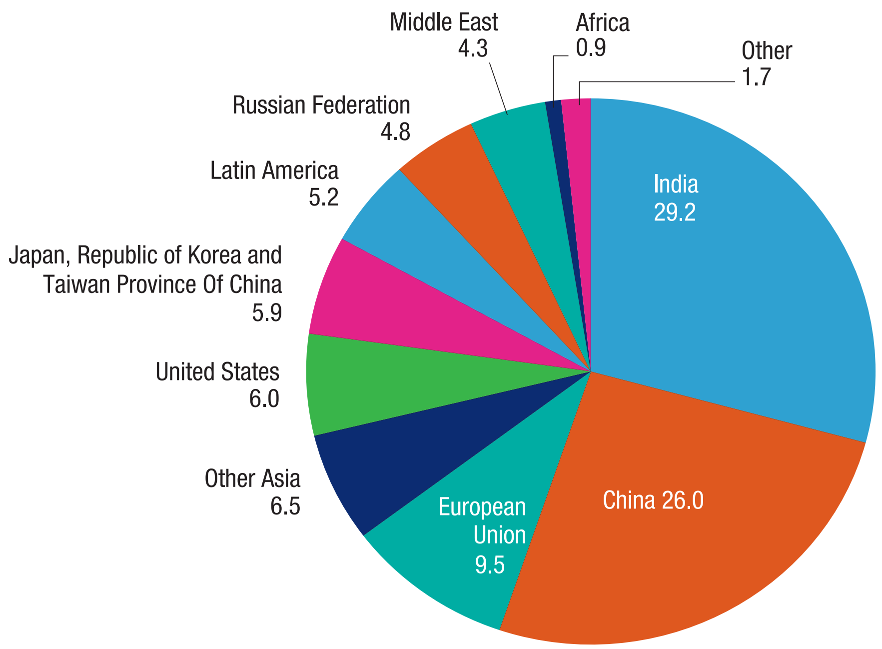

*Source:* United Nations Economic and Social Council (2017).

**Figure 2.2 Researchers (in full-time equivalent) per 1 million inhabitants, by region, 2000–2014**




*Source:* United Nations Economic and Social Council (2017).

**Figure 2.3 Distribution of global first university degrees in STEM, by country/region, 2012 (Percentage)**




*Source:* National Science Board (2016).
*Note:* Data for India refer to 2011.

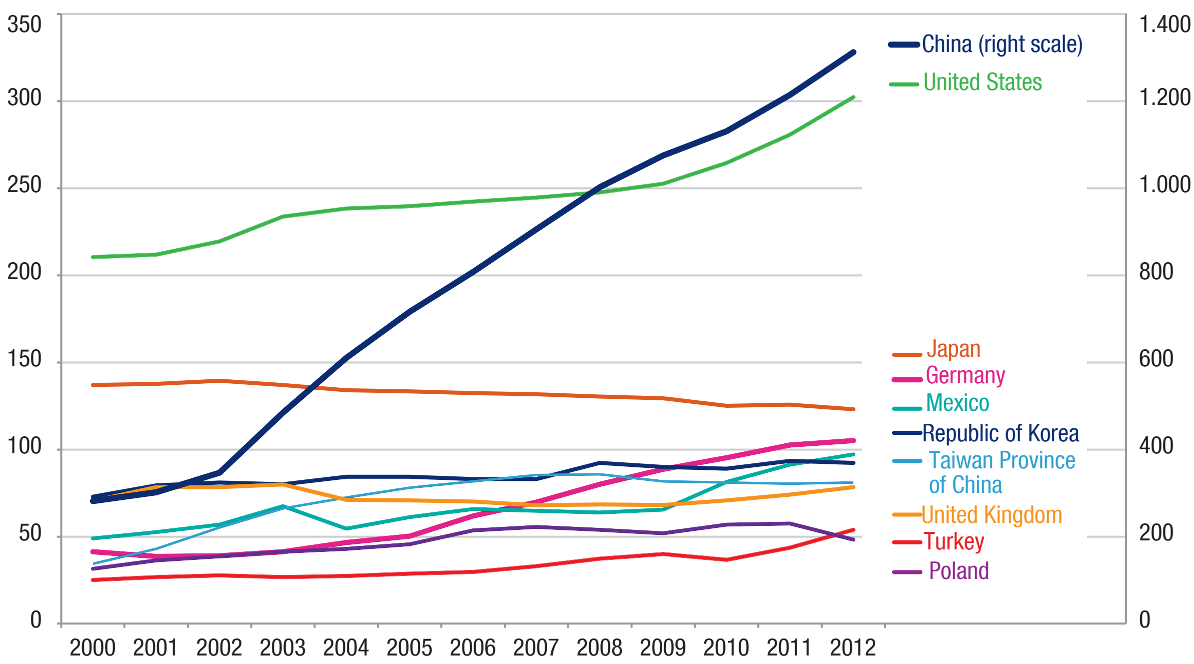
a first university degree in 2012 in countries with data available, more than 5 million were in STEM subjects.[43] Among these countries, universities in Asia (excluding the Middle East) accounted for more than two thirds of STEM graduates, mostly in India (29.2 per cent of world total) and China (26 per cent) (figure 2.3). While the European Union and the United States follow India and China in the rankings, they have much smaller proportions of STEM graduates. Latin America accounted for just 5.2 per cent of graduates, and Africa for less than 1 per cent. Despite substantially increasing both the quantity and quality of its STEM research output, sub-Saharan Africa still accounts for less than 1 per cent of the world's research output in this area (Blom et al., 2016).

STEM degrees accounted for 32 per cent of total degrees in Asia, above the global average of 25 per cent. In China, the proportion was still greater, at 42 per cent, although this share has declined from 57 per cent in 2000. Even in the developed world, the share of STEM in total bachelor's degrees was below the world average in 2012, at 18.5 per cent in the European Union and 16.7 per cent in the United States. In Africa, it was just 7.2 per cent, and 14.4 per cent in Latin America. However, it is important to note that regional averages may mask wide differences among countries – China, for example, is an outlier in its region. In Latin America, for example, the share of STEM graduates was 22.8 per cent of the total in Mexico, but only 10.5 per cent in Brazil. In Africa, the share was 29.5 per cent in Ethiopia, but 8.9 per cent in Ghana.

In China, Germany, Mexico, Taiwan Province of China and Turkey, the number of STEM first degrees at universities more than doubled between 2000 and 2012 (figure 2.4), with a particularly large increase of 366 per cent in China. Numbers increased by 43 per cent in the United States, 53 per cent in Poland and 27 per cent in the Republic of Korea. There was a much smaller increase in the United Kingdom (11 per cent), and a decline of 10 per cent in Japan over the same period.

[43] Only countries for which relatively recent data are available are included in the database, mainly countries in the Americas, Asia and Europe. Consequently, the total numbers for the world are an underestimation.

**Figure 2.4 First university degrees in STEM, selected countries, 2000–2012 (Thousands)**




*Source:* National Science Board, 2016.

The impact of the R&D gap is by no means limited to the ability of countries to generate new knowledge or to identify and adapt knowledge generated elsewhere to their own context. The R&D gap also affects the capacity of countries to undertake foresight exercises that allow them to chart the path of their STI development on their own terms. R&D gaps limit the ability of developing countries to assess not only the technological but also the economic, social and environmental opportunities, challenges and risks that may emerge from frontier technologies, and put in place the relevant policy frameworks. Synthetic biology for example is a key frontier technology with significant potential impact on food security, health and the environment. Without adequate R&D capabilities, a country will struggle to establish and implement the biosafety regulatory framework needed for the development of competitive productive capacity in this sector.

## C. BUILDING SKILLS FOR COMPLEMENTARITY WITH NEW TECHNOLOGIES IS CRITICAL

Research and development is not the only gap that needs to be addressed if developing countries are to benefit fully from frontier technologies. As discussed in chapter I, digitalization and automation will give rise to profound changes across many sectors, including manufacturing, which has historically driven structural transformation and provided better jobs for workers displaced from lower productivity sectors. A labour force with skills that are complementary to technological advances is essential if technological change is to be compatible with social inclusion. Rapid technological progress requires the labour force to develop a broader range of skills, focusing on humans' comparative advantage, to increase employability. In the new technological landscape, there is a need for generic, core or fundamental skills, such as literacy, numeracy and basic academic skills, together with basic financial and entrepreneurial skills and, increasingly, basic digital and even coding skills. Indeed, the predominance of digital technologies in the Fourth Industrial Revolution makes mastering digital skills ever more relevant (see UNCTAD, 2017a). Access to the Internet is also an important influence, providing an enabling environment for innovation (see box 2.1).

Advanced cognitive skills, such as STEM, may be relatively difficult for technology to replicate. Other skills that are gaining increasing importance are those that are most inherently human in nature, and thus difficult for robots and machines to emulate – variously termed soft skills, transversal or transferable skills, and behavioural, interpersonal and socio-emotional skills. So, too, are competencies and attitudes such as creativity, intuition, imagination, curiosity, risk-taking, open-mindedness, logical thinking, problem-solving, decision-making, the ability to engage in contact and interact with others (empathy and emotional intelligence), communication, persuasion and negotiation skills, networking and teamwork, and the capacity to adapt and learn new abilities. Education and training policies at all levels should aim to strengthen such abilities, skills and attitudes among current and future workers.

As technology advances mismatches may emerge between the demand for skills and their availability. These can be minimized by properly assessing future needs. The relationship between technology and education in the context of the labour market has been depicted as a "race between education and technology", in which "if workers have flexible skills and if the educational infrastructure expands sufficiently, then the supply of skills will increase as demand increases for them" (Goldin and Katz, 2007:26). The rapid pace of technological progress and increasing instability in the labour markets thus requires education policies to react with agility, while education and training systems may require significant transformations.

However, there are indications that educational institutions are not keeping pace with technological advances during the current transition period. Many countries are witnessing skills shortages in the field of digital technologies and many employers report difficulties in filling high-skill vacancies. A 2016 worldwide survey on talent shortage found that 40 per cent of employers reported difficulties in filling positions (ManpowerGroup, 2016). Melguizo and Perea (2016) found Latin America to be the emerging region where firms encountered the greatest problems arising from a lack of adequate skills, well ahead, not only of emerging Asia and Europe, but also of sub-Saharan Africa. At the same time, many workers feel that they are overqualified for their jobs (Citi GPS and Oxford Martin School, 2016).

**Box 2.1 Technology readiness and innovation**

The scope of digital advances is ever-expanding, with greater convergence of digital, physical and biological technologies; but taking advantage of the immense potential benefits requires capabilities to respond effectively to these changes. This in turn requires an analysis to identify gaps in innovation and technology readiness. The Global Competitiveness Index developed by the World Economic Forum (WEF) includes a **sub-pillar** on innovation encompassing capacity for innovation, quality of scientific research institutions, company spending on R&D, university–industry collaboration on R&D, government procurement of technology products, availability of scientists and engineers and Patent Cooperation Treaty patents (WEF, 2017). Comparing this sub-pillar with those on technology readiness and particularly ICT use, an appreciation of a suggestive relationship can be distinguished. According to WEF, ICT use (percentage of Internet users, fixed broadband, Internet bandwidth, and mobile broadband subscriptions) can be indicative, as ICT clearly has an influential role in innovation. In India and Indonesia, for example, only a third of the population are active Internet users, and very few have access to fixed broadband, limiting technology readiness (WEF, 2017). By contrast, access to mobile broadband subscriptions was found to be relatively equal across countries (except for India), suggesting that mobile phones can be an enabling tool for ICT use.

**Innovation and ICT use (WEF)**

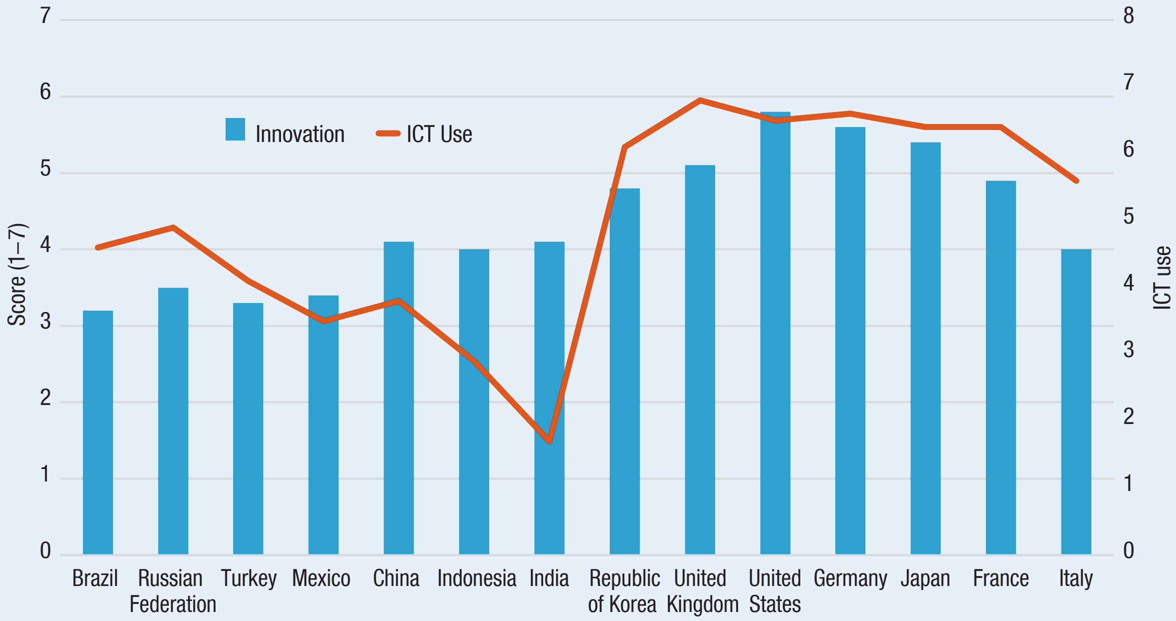



*Figure:* Technology readiness and innovation analysis of large advanced and emerging economies, compared with the percentage of Internet users in the respective countries.
*Source:* WEF (2017).

Anticipating changes in skills requirements will be crucial for education policies to address these mismatches quickly. Big data analysis may play a useful role in monitoring labour market changes and identifying likely skills shortages. This also requires a holistic approach, entailing collaboration among policymakers, education and training systems and employers, to match supply and demand for the skills required. Such a holistic approach is also needed for a successful overall lifelong learning system (Riad, 2017). It should also include families, who play an important role in providing a positive environment for learning. The role of lifelong learning in harnessing emerging technologies for sustainable development is discussed further in chapter IV.

The need for constant updating of skills requires rethinking of the formal education system to make learning to learn a key objective. Addressing the employment challenges of the new technological era requires curricula to be adapted to teach the skills that are becoming more significant. Development of the required skills and competencies, as well as motivation for lifelong learning, should start in early childhood education. Children will need to learn foundational skills – including digital and financial literacy and learning to learn competencies, as well as numeracy and literacy – and to focus more on transferable and socio-emotional skills. What matters is not merely acquiring knowledge, but increasing the capacity to learn: learning how to learn is fundamental to developing new skills and competencies later in life, initiating a cumulative process through which learning generates further learning.

Transforming the education and training systems will also require changes in the way teachers work and in their pedagogical methods, and improvements in the quality of education. Indeed, the quality of education is becoming more important than the quantity of education received. Education system reforms should include adoption of a more flexible and open approach (UNESCO, 2015). Education should therefore be reoriented from memorizing and theory to acquiring knowledge and learning in a more practical, applied and experimental manner, through projects and interaction among students. The role of teachers should be to facilitate learning and to provide guidance for the student to explore and learn from different sources and to use knowledge and information creatively to apply it to different situations. Education should move away from academic certification and specialization to a system increasingly based on the development of skills, competencies and capacities for continuous learning. This will require innovation in education and training, and will necessarily imply retraining of teachers and changes in mindsets.

Innovation in education (along with performance, inclusion and finance) is one of the four education transformations to achieve a learning generation (International Commission on Financing Global Education Opportunity, 2016). The imperative for innovation in education is emphasized in the 2014 World Innovation Summit for Education Survey, "School in 2030". Teachers will need to adapt to the new ways in which students now learn, and to tailor curricula to individual needs. Digital and online tools have an increasingly important role in assisting teachers and students, from providing students with laptops or tablets to the use of more advanced technologies such as gamification and virtual reality. An example is the collaborative online platform Educopedia, created in 2010 by the Municipality of Rio de Janeiro, Brazil, which supports teachers in the creation and sharing of teaching materials online and increases students' motivation by providing multimedia resources. The future education system is likely to be a hybrid, combining online content and global learning networks with face-to-face classroom education in a holistic learning experience (World Innovation Summit for Education, 2014).

However, while the development of digital skills is an important part of the response to frontier technologies, a prior condition for success is addressing the fundamental divide that seriously disadvantages the majority of the global population in access to STI. The next section addresses the gender divide in STI.

## D. TECHNOLOGICAL AND DIGITAL GENDER DIVIDES

**Sustainable Development Goal 5: Achieve gender equality and empower all women and girls**

### 1. Women in science and technology

While women scientists can be key contributors to finding solutions to global economic, social and environmental challenges, women account for only a small proportion of researchers globally. Moreover, the gender gap is particularly evident in fields crucial to the transformation required for sustainable development and to harnessing the benefits of frontier technologies, such as STEM, information technology and computing. UNESCO (2016) depicts the participation of women in research as a leaky pipeline: while women participate more actively than men at the bachelor's and master's degree levels, accounting for 53 per cent of the total, this proportion falls significantly at the Ph.D. level, and only 28 per cent of researchers were female in 2013.

There are significant regional differences in the proportion of female researchers. Most data are presented in terms of the total number of people employed in R&D, treating full-time and part-time staff equally. Regional averages include only available data, and lack of gender-disaggregated data is a major obstacle to analysis (UNESCO–UIS, 2017b). Subject to these caveats, the regions with the lowest share of female researchers in 2014 were South and West Asia (19 per cent), East Asia and the Pacific (22.9 per cent) and Africa (30.4 per cent), while the highest shares were registered in Central Asia (47.2 per cent) and Latin America and the Caribbean (44.7 per cent) (table 2.1). There are also significant variations within regions. In Asia, Malaysia, the Philippines and Thailand have achieved gender parity; in Africa, Namibia and South Africa are close to gender parity. In Latin America, women researchers are the majority in the Plurinational State of Bolivia (63 per cent) and the Bolivarian Republic of Venezuela (56 per cent). In most high-income countries, by contrast, the proportion of female researchers is relatively low (UNESCO, 2016).

**Table 2.1 Share of female researchers, by region**

| Geographical region | 2014 |
|---|---|
| World | 28.8 |
| Arab States | 39.9 |
| Central and Eastern Europe | 39.6 |
| Central Asia | 47.2 |
| East Asia and the Pacific | 22.9 |
| Latin America and the Caribbean | 44.7 |
| North America and Western Europe | 32.2 |
| South and West Asia | 19 |
| Sub-Saharan Africa | 30.4 |

*Source:* UNESCO–UIS (2017b).

Focusing on engineering and technology, shares of female researchers differ widely among countries, with shares below 10 per cent in Angola, Botswana, Ethiopia, Ghana, Japan, Malawi, Oman, Palestine, Saudi Arabia and Togo register shares of below 10 per cent, but above 40 per cent in Azerbaijan, Guatemala, Kazakhstan, the former Yugoslav Republic of Macedonia, Malaysia, Mongolia and the Bolivarian Republic of Venezuela. While the share of women in tertiary engineering education has declined relative to other sciences in many countries, there are some regional exceptions. For example, the proportion of women engineers has increased in sub-Saharan Africa (although it remains below 20 per cent), the Arab States and parts of Asia. Women are also a minority among graduates in computer science, the proportion declining steadily since 2000, particularly in high-income countries. Women are also underrepresented in the higher levels of decision-making related to science and technology research (UNESCO, 2016).

Reasons for the limited numbers of women in STI and ICT include: gender differences in access to and quality of education; gender differences in employment opportunities; stereotypes; lack of role models, mentorship and sponsorship; workplace culture; and issues related to work-life balance (UNWOMEN et al., 2017). Despite significant progress towards gender parity, these factors contribute to a persistent gap, particularly in the number of women graduating and working in STEM fields. The global gender gap in STEM graduates is 47 per cent: 30 per cent of male students graduate in STEM subjects, but only 16 per cent of female students (WEF, 2016). Even in the United States – a leading country in STI – women represent only 25 per cent of workers in STEM fields (U.S. Chamber of Commerce Foundation, 2015).

## 2. Gender divides in manufacturing employment, including ICTs

In developing countries, particularly LDCs, women are employed mostly in agriculture and services, very often in the informal economy. While the services sector has overtaken agriculture as employer of both women and men, women are employed mainly in lower-paid and lower-skills jobs rather than in advanced and high-tech services (United Nations Economic and Social Council, 2016). For both men and women, employment is lowest in industry, which accounted for around 16 per cent of employment for women and 25 per cent for men from 1995 to 2005, increasing thereafter to reach 18 per cent for women and 27 per cent for men in 2015. The proportion of women engaged in industry in 2015 was below 20 per cent in all regions except East Asia (30 per cent) and South Asia (21 per cent), while the proportion for men was in the range of 20–40 per cent in all regions except sub-Saharan Africa and Oceania (United Nations Statistics Division, 2015).

In the manufacturing sector, the proportion of female employees showed a remarkable decline between 1991 and 2014, from 50 per cent to 38 per cent (United Nations Industrial Development Organization (UNIDO), 2016). Here, women work mainly in labour-intensive jobs, mostly in low-tech industries such as food and beverages, textiles and apparel. At earlier stages of industrialization, this may favour women's employment, as these industries often follow a growing trend, increasing their job opportunities. At more advanced stages of industrialization, however, the concentration of women's employment in these sectors means that they may be excluded from better paid jobs in the medium- and high-tech manufacturing sector (UNIDO, 2013). In 2015, female employment in manufacturing was slightly lower than that of males in low-income and lower-middle-income countries, higher in upper-middle-income countries, and significantly lower in high-income countries (ILO, 2016). Unfortunately, more detailed analysis is precluded by the lack of appropriate gender-disaggregated data in manufacturing value added and employment.

Women are also severely underrepresented in the key area of ICTs, accounting for only 30 per cent of total workers in the digital sector in the European Union, for example.[44] Underrepresentation occurs at all levels, but particularly in decision-making positions. Women also represent less than 40 per cent of total employment in some of the top technology companies. A 2014 survey focusing on the gender balance in 20 leading technology companies showed that only 11 per cent of executive committee members were women (20-first, 2014).

## 3. The gender gap in mobile ownership and Internet use

**Sustainable Development Goals Target 5.B: Enhance the use of enabling technology, information and communications technology, to promote the empowerment of women;**

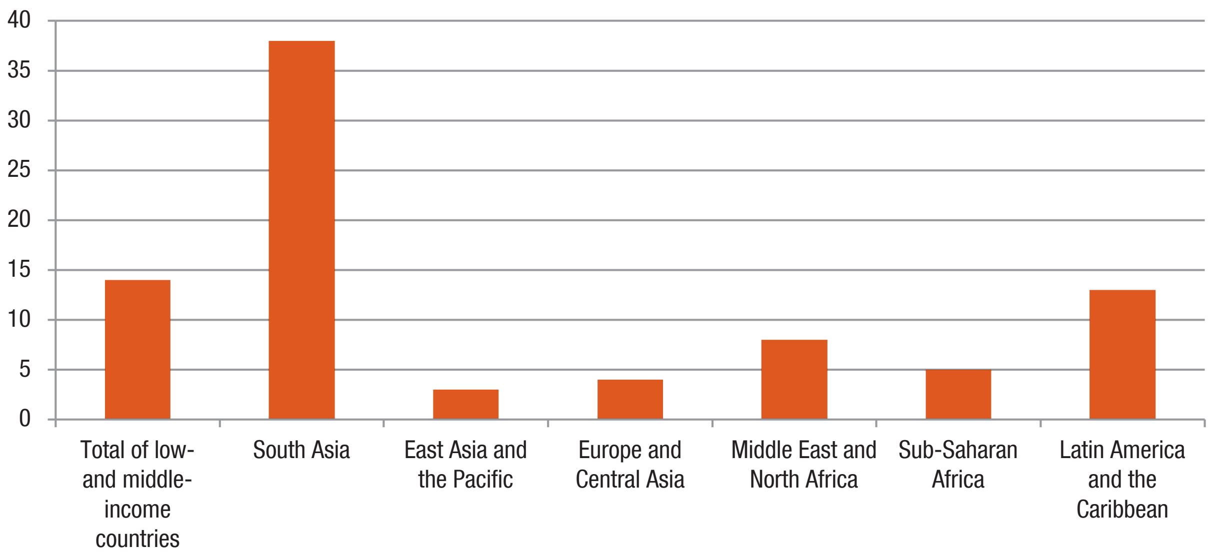
**Indicator 5.B.1: Proportion of individuals who own a mobile telephone, by sex**

The gender gap in mobile ownership is defined as one minus the proportion of males who own mobile phones divided by the proportion of females who own mobile phones. While gender-disaggregated data on mobile ownership do not appear to be readily available, GSMA (2015) suggests a gap of around 14 per cent in 2014 in low- and middle-income countries, equivalent to about 200 million females. The greatest gaps were registered in South Asia (38 per cent) and Latin America and the Caribbean (13 per cent). Overall, more than 1.7 billion women in low- and middle-income countries do not own a mobile phone.

The gender digital divide is also evident in data on Internet use. The proportion of women using the Internet is lower than that of men in two thirds of countries. The Internet use gap (defined as the gender gap in mobile ownership, but based on Internet use) is almost 11.6 per cent globally, up from 11 per cent in 2013, with a marked difference between developing countries (16.1 per cent) and developed countries (2.8 per cent) (ITU, 2017). There are wide differences among regions and by level of development, with LDCs and sub-Saharan Africa showing the greatest gaps at 32.9 per cent and 25.3 per cent, respectively. These are also the only country groups where the gap widened between 2013 and 2017. The gender gap is also significant in the Arab States and the Asia and Pacific region (figure 2.6).

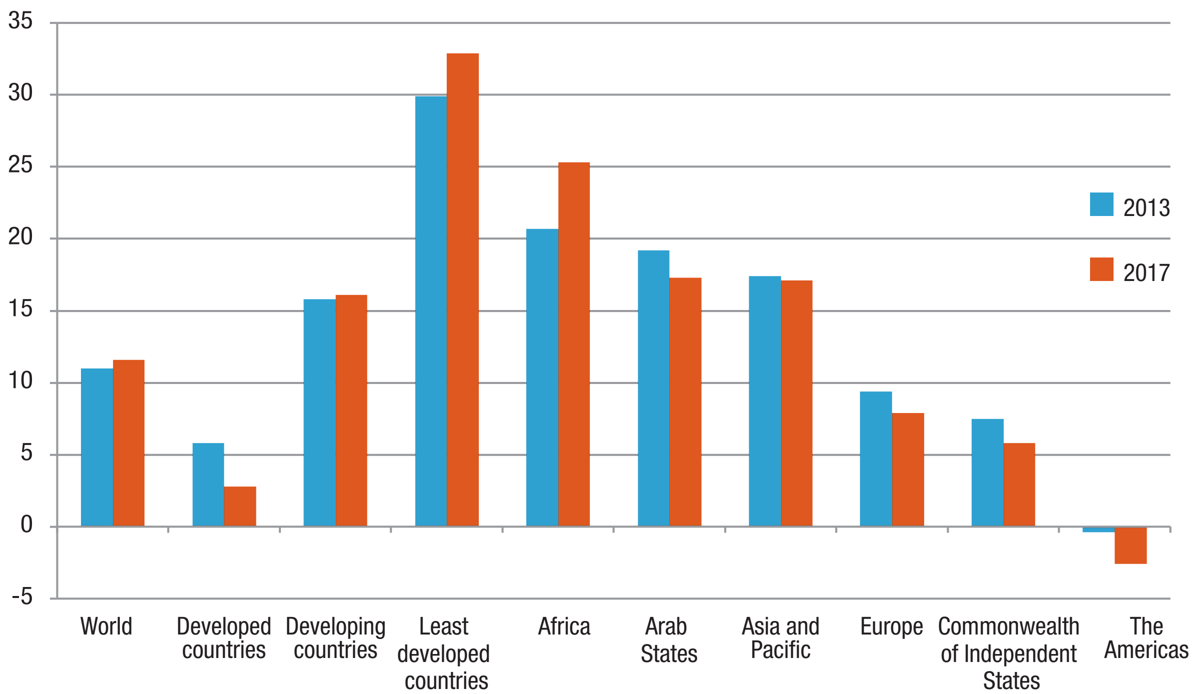
44 See European Commission, Women in Digital, available at https://ec.europa.eu/digital-single-market/en/women-ict (accessed 21 March 2018).

**Figure 2.5 Gender gap in mobile ownership in low- and middle-income countries, 2014 (Percentage)**




*Source:* GSMA, 2015.

**Figure 2.6 Gender gap in Internet use by level of development and region, 2013 and 2017 (Percentage)**




*Source:* ITU (2017).

# E. THE ENERGY GAP AND THE DIGITAL DIVIDE

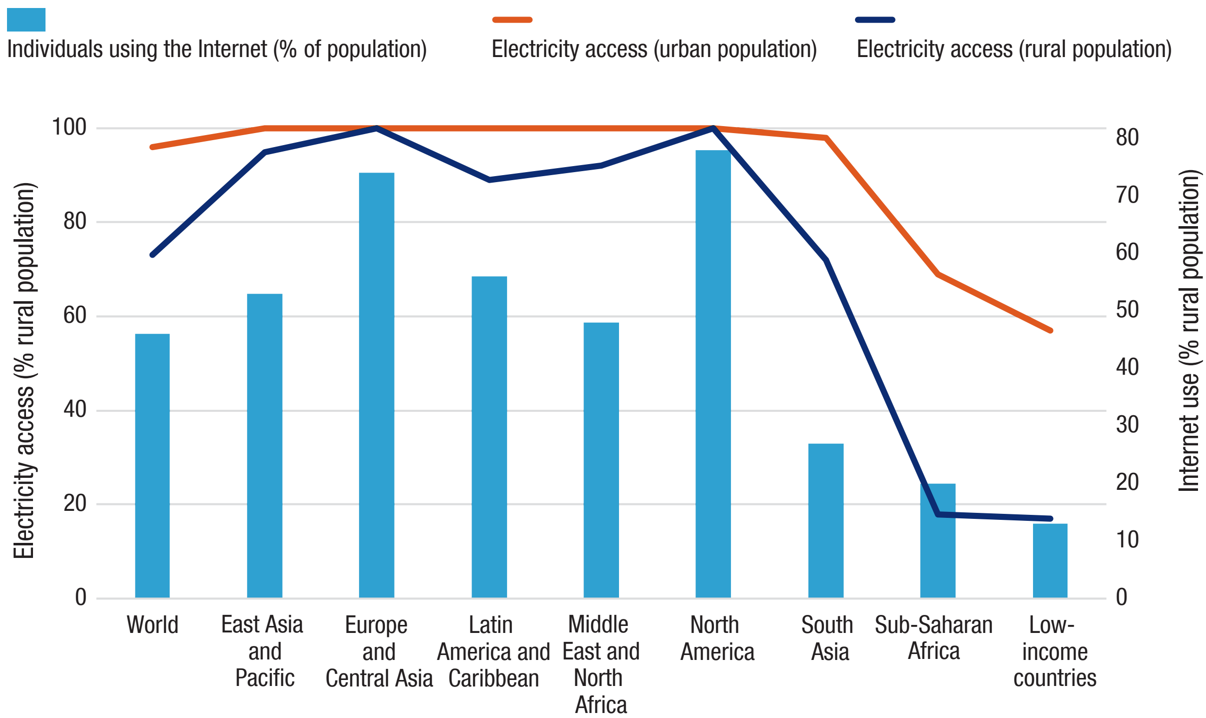
**Sustainable Development Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all**

As discussed in chapter I, the Internet is the major platform of platforms through which frontier technologies deploy their effects. Access to the Internet is key to expanding economic opportunities and improving service delivery. For example, the growth of the digital economy is entirely dependent on the quality of Internet access available to firms and households. Access to the Internet, in turn, requires reliable access to electricity. As UNCTAD (2017b) notes, accessible, affordable and reliable electricity is central to structural transformation and frontier technologies can accentuate the transformative role. As discussed in chapter I several frontier technologies can improve access to electricity and the management of electricity networks, as well as increasing the role of renewable sources of electricity, giving rise to a positive loop. Energy consumption is also closely related to rapid growth of the ICT industry, which has been estimated to be responsible for 3-4 percent of total global electricity consumption, although network fibres are reducing energy requirements for high-volume data traffic (World Bank, 2016).

Electricity access is generally biased towards urban areas (ibid.:chapter 1), and rural electrification typically reaches wealthier homes and larger schools and facilities first.[45] Thus, poorer communities typically remain excluded from reliable and affordable electricity as electrification proceeds. Disaggregating electricity access between urban and rural populations provides a key insight into Internet use (figure 2.7). This is particularly evident in sub-Saharan Africa, where electricity access in 2014 was 69 per cent in urban areas but only 18 per cent in rural areas in 2014, while Internet use was only 20 per cent in 2016. Similarly, South Asia has a large urban–rural gap in electricity access, with Internet use a little higher at 27 per cent. Greater Internet use in South Asia may partly reflect greater affordability, with fixed broadband average costs of $7 per month versus $32 in sub-Saharan

45 UNCTAD (2017b) and United Nations Department of Economic and Social Affairs (2014).

**Figure 2.7 The relationship between Internet use versus electricity access in urban and rural population (Percentage)**




*Source:* World Bank[46]

Africa. This analysis is suggestive of a connection between electricity access and Internet use, and of the interconnected exclusion of rural populations from both.

Energy consumption is also closely related to rapid growth of the ICT industry, which has been estimated to be responsible for 3-4 per cent of total global electricity consumption, although network fibres are reducing energy requirements for high-volume data traffic.[47]

Decentralized energy systems, based on mini or micro grids using renewable energy technologies, offer considerable potential to address the issue of rural access to electricity, particularly in LDCs – although there are important technological, economic, financial and governance issues to overcome (UNCTAD, 2017b). Capabilities in these areas should be encouraged, to address access to electricity and to the Internet in parallel. This could confer multiple benefits, particularly in light of the vast underserved rural populations in most LDCs.

## F. CONCLUSIONS

The analysis presented in this chapter demonstrates the significant and persistent divide between countries in STI capabilities – a divide that can both perpetuate existing inequalities and create new ones. The greatest divide is in the LDCs, which will need to make the greatest progress by 2030 if the Sustainable Development Goals are to be achieved. More than ever, it is imperative for developing countries to strengthen their efforts towards technological catch-up with advanced countries and to build knowledge-based economies. In a digital age, a crucial factor is the premium on those skills that enable workers to complement rather than compete with machines. National strategies in developing countries are also needed, together with international support measures, to ensure that they are not left behind,

46 World Bank, World Development indicators: The information society. Available at http://wdi.worldbank.org/table/5.12# (accessed 21 March 2018); and World Development Indicators: Sustainable energy for all. Available at http://wdi.worldbank.org/table/3.13 (accessed 21 March 2018).

47 World Bank (2016): Sector Focus 5, Energy.

and to enable them to reap the potential benefits of frontier technologies. The next chapter discusses how governments and other STI stakeholders can collaborate to develop the foundations of STI policy for development to address the gaps presented here and create the conditions to exploit the full potential of frontier technologies – and, equally important, of established technologies – to support the implementation of the Sustainable Development Goals.

**Box 2.2 Key messages and conclusions**

(a) There are large divides among countries in technical skills and R&D efforts and capacity. Most developing countries are lagging behind, especially the LDCs.

(b) The skills base of countries will need to evolve to take advantage of frontier technologies and adapt to rapid technological change. Anticipating skills changes will be crucial for education policies to address these skills mismatches quickly.

(c) Some skills will be hard to automate. These include advanced cognitive skills and soft skills that are most inherently human in nature.

(d) Education and training systems will need to be reformed and become more flexible to match skills with changing skills requirements. Learning to learn will itself become a more valuable skill.

(e) There are gender gaps in technical education, employment in the manufacturing and ICT sectors, and in access to ICTs and the Internet.

(f) Mutually reinforcing divides in access to electricity and in access to the Internet are a serious bottleneck to the effective deployment of frontier technologies and exploiting their potential for transformation.

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# CHAPTER III

# FOUNDATIONS OF STI POLICY FOR SUSTAINABLE AND INCLUSIVE DEVELOPMENT

The overarching challenge for developing countries in reaping the benefits of STI is to learn, adopt and disseminate knowledge and technologies to promote sustainable development. For developing countries, this challenge is equally vital with regard to frontier technologies and those that are more established in international markets, which many developing countries still face difficulties in accessing, adapting and deploying to their full potential. Without appropriate STI policies, no form of technology is likely to deliver progress in the global development agenda. Such progress requires an environment that nurtures learning and innovation – and the dedication of resources, time and concentrated efforts – to build and manage effective innovation systems.

This chapter therefore provides an overview of the foundations of STI policy in the context of the 2030 Agenda for Sustainable Development, drawing on UNCTAD's experience in reviewing STI policy frameworks in developing countries. Section A outlines the prerequisites for effective innovation systems in terms of capabilities, connections and the enabling environment, and addresses key policy issues in the areas of innovation financing and intellectual property protection; section B places STI policy in the wider context of overall development strategies, highlighting the importance of policy coherence and coordination; and section C discusses the reorientation of STI towards the goals of sustainable and inclusive development in the context of the 2030 Agenda.

## A. INNOVATION SYSTEMS: BUILDING AN ENABLING ENVIRONMENT FOR STI

The prevalent view of STI policies has evolved from a linear model driven primarily by science to a model based on innovation systems, in which successful innovation is seen as a response to market demand and systemic stimuli outside R&D facilities and laboratories. The latter is now the main theoretical foundation of innovation policies in developed and developing countries alike.

There are many different definitions of innovation systems. The common theme is the idea that the extent and nature of innovation depend not only on the knowledge available to individual firms, but also on their ability to interact (within a given economic and institutional environment) with each other and with research organizations and government agencies to produce and disseminate economically valuable knowledge. Such systems develop over time, co-evolving with their economic, political, social and environmental contexts. They are less developed and more prone to systemic failures and structural deficiencies in developing than in developed countries (Chaminade and Padilla Pérez, 2017).

Firms are at the core of innovation systems, by virtue of their central role in connecting different types of knowledge to bring innovative technologies, products and services to the market (Metcalfe and Ramlogan, 2008). However, the innovation system is a broader concept, also encompassing research and education systems, government, civil society and consumers. The key aspects of innovation systems are the capabilities of these various actors, the connections among them, and the enabling environment for innovation that they create.

### 1. Capabilities of actors in the innovation system

The capability of **firms and entrepreneurs** to absorb new knowledge and transform it into innovation is fundamental to any effective innovation system. This includes a range of capabilities, from absorptive capacity (to assimilate existing knowledge and technology) to the ability to engage in advanced R&D and technological innovation. Firms' capacities to introduce innovations in local, national and international markets are a prerequisite for technological upgrading and improving a country's productive capacity. Technological learning is not limited to formal mechanisms of R&D: learning by doing and by interacting with users, clients and suppliers plays a critical role in many contexts.

With the necessary scientific and technological capabilities, research actors can offer various services in support of innovation, ranging from support to technology adoption (e.g. testing) to fully fledged R&D and demonstration processes. Their ability to learn and apply knowledge to innovation processes is thus critical to technological learning and building the local knowledge base. Education systems can improve the quality of human capital available to firms, governments and research institutions. They need to respond to changing demand for specific skills, in order to improve the learning capabilities and absorptive capacities of firms and other actors.

The capability of **governments** to negotiate and establish priorities and to build capabilities and connections is critical to the formation of any innovation system. Policymakers can deploy a range of instruments to support innovation processes directly and to tackle systemic failures inhibiting the performance of the innovation system. A coherent STI policy mix is crucial, to provide a stable and predictable environment for innovation. Governments play a key role in aligning STI priorities with the challenges of sustainable development and the Sustainable Development Goals.

While **civil society and citizens** are rarely considered as key actors in innovation systems, NGOs, social enterprises and engaged citizens can be drivers of technological change and play a critical role in the adoption and assimilation of new technologies. Civil society can also assume a mediating role between the developers of new technologies and societal needs. In developing countries particularly, civil society can also be instrumental in testing, promoting and diffusing innovations designed to benefit the most disadvantaged communities.

In developing countries with nascent innovation systems, most firms and other actors need first to develop a basic capacity to learn how to adopt, assimilate and diffuse existing knowledge and technologies. Building absorptive capacity and technological upgrading often relies on local actors' access to and assimilation of foreign knowledge and technology as well as technologies developed by other local firms (Amsden, 2001; World Bank, 2008; Metcalfe and Ramlogan, 2008; Malerba and Nelson, 2012; UNCTAD, 2007, 2017a). While foreign knowledge may be accessible through trade, foreign direct investment (FDI), licensing, migration, participation in global value chains and imitation, successful technology transfer depends on the development of local absorptive capacity (Cohen and Levinthal, 1990). Technology transfer should thus be seen as a complement to, not a substitute for, efforts to build endogenous innovation potential.

## 2. Connections in the innovation system

The formation of connections between actors is an essential part of the creation of innovation systems (Metcalfe and Ramlogan, 2008). Knowledge flows and partnerships between firms in different sectors and between firms and researchers, for example, facilitate learning, technology adoption and the development of new technologies. Networking and collaboration capabilities are crucial to these linkages, as well as to flows of key resources, including finance and human capital. Facilitating innovation collaboration in response to specific societal challenges requires particular capacities and skills,and is often supported by governments.

While there may be **innovation intermediaries** or **knowledge and technology brokers** specializing in facilitating knowledge exchange and innovation collaborations, all actors in the innovation system should build capabilities to engage in different forms of collaboration, from information exchanges to the formation of innovation partnerships that may become actors in their own right (e.g. clusters or competence centres).

Mature innovation systems encourage local, national and international collaborations that cut across economic sectors, areas of technology and scientific disciplines. Building collaboration capabilities between national actors is fundamental to strengthening a country's endogenous potential over the long term. Collaborations along supply and value chains, including organizations that provide financing, contribute to demand responsiveness and social acceptance as well as the commercial viability of innovation. For developing countries with an underdeveloped local knowledge base and limited access to market intelligence, developing links with foreign firms, funders and research centres is one of the key steps. However, such links will only be operative if some local capacity has been built previously through investment in education and training.

The emergence of successful innovation networks is a long-term process based on a shared vision, common goals and trust. While innovation collaboration can occur spontaneously, in many areas – notably those related to social and environmental challenges – it requires active facilitation by government or non-government actors. Government support to networking may focus on specific locations (e.g. science and technology parks) or sectors (e.g. competence centres focused on specific topics).

## 3. The innovation system as an enabling environment

The **five building blocks of innovation systems as an enabling environment** are (see figure 3.1):

(a) The regulatory and policy framework;

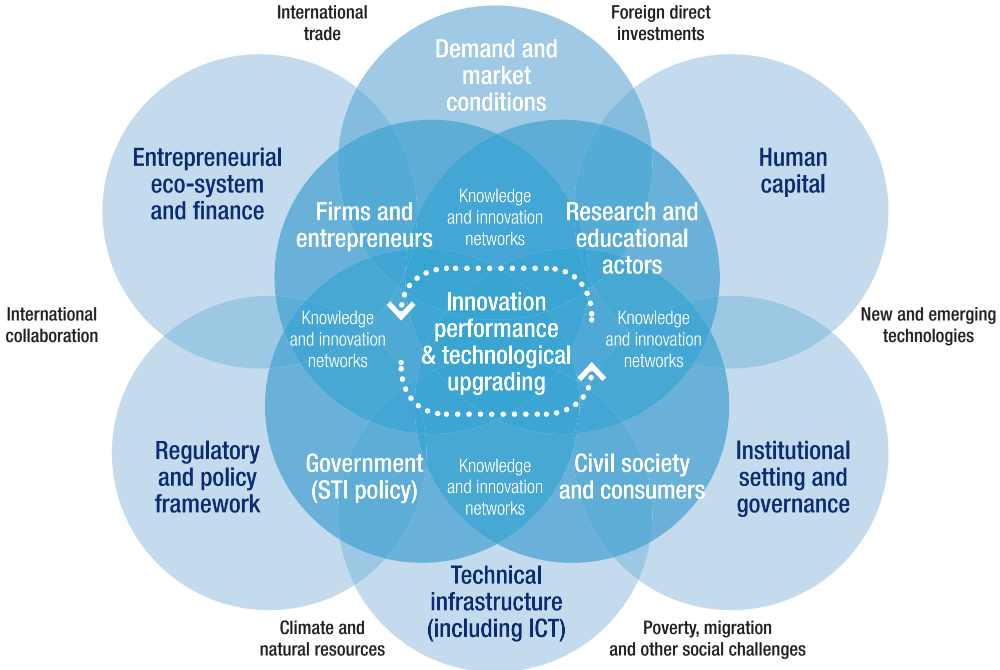
(b) The institutional setting and governance;

(c) The entrepreneurial ecosystem and access to finance;

(d) Human capital; and

(e) Technical and R&D infrastructure.

**Figure 3.1 Systemic foundations of innovation and technological upgrading**




*Source:* UNCTAD secretariat.

**The regulatory and policy framework** provides incentives for established and emerging firms to invest in learning, knowledge and innovation (UNCTAD, 2007; Chaminade et al., 2009; World Bank, 2010). Policies should provide a stable and predictable environment to facilitate long-term planning by firms and other innovation actors, including organizations that finance technology and innovation. For example, stable long-term targets allow firms to assess and manage the risks involved in innovation investments. The policy framework should be comprehensive and comprise various STI policy instruments, which should be coherent internally and consistent with other key policy areas, through alignment with industrial trade, FDI and competition policies (Amsden, 2001; UNCTAD, 2013, 2015c). The integration of STI policies into overall development strategies is discussed further in section B below.

**The institutional setting and governance** encompass legal rules, standards and norms, and the organizations and governance mechanisms used to create and enforce them. Institutions should incentivize actors to invest in productive rather than rent-seeking activities (Rodrik, 2007; Reinert, 2007; Cimoli et al., 2009). Of particular importance are the organizations designed to support firms in learning, knowledge creation and the accumulation of technological capabilities (Nelson, 1993; Cimoli et al., 2009); and specialized bodies for financing technology and innovation, (Edquist, 1997; UNCTAD, 2007, 2015b) (see subsection A.4 below). Other relevant institutions include education and training organizations; ministries, departments and agencies overseeing STI policy; and organizations central to metrology, standards, testing and quality systems. The wider concept of governance also includes actors such as NGOs and grass-roots movements active in promoting new forms of innovation, such as those discussed in chapter IV.

**The entrepreneurial ecosystem and access to finance** are critical to business incubation and encouraging the growth of innovative companies. An entrepreneurial ecosystem oriented towards supporting innovation should provide flexible access to finance, particularly for young entrepreneurs and innovative companies. Ensuring access to financial support for promising innovative projects requires not only the availability of funds, but also organizational capabilities and policy frameworks. Firms and entrepreneurs need to develop managerial competencies to formulate credible business plans and to assess project risks, while organizations financing innovation for sustainable development should adapt their instruments to make them more readily accessible to young entrepreneurs and start-ups with relevant propositions. Governments can contribute by ensuring a stable regulatory framework and promoting financial instruments catering to the needs and capabilities of SMEs and entrepreneurs.

**Human capital** allows firms to engage in technology adoption and innovation processes, and to harness the wider benefits of STI, including in the poorest and most remote communities (Lucas, 1988; Lloyd Ellis and Roberts, 2002; World Bank, 1993, 2010; Malerba and Nelson, 2012). Human capital relies on all levels of education, and includes both the technical and the managerial skills involved in innovation activities, from R&D, design and engineering, to technology brokerage and networking. It is also critical to learning to design and implement STI policies and develop effective institutions (Bell, 1984; Bell and Pavitt, 1993, 1995; Lall, 1992, 1996; UNCTAD, 2007). A strong technical and vocational education system must provide both basic science, technology, engineering and mathematics (STEM), as well as management skills. As discussed in chapter II, new technologies have greatly increased the importance of skills such as problem-solving, teamwork, creativity, learning to learn and ICT skills.

**Technical and R&D infrastructure** comprises basic technical infrastructure (e.g. water, energy, ICT, transport and urban structures); specialized infrastructure supporting R&D, demonstration and innovation processes (e.g. laboratories, testing and certification facilities); and existing technologies. Basic technical infrastructure is one of the key factors promoting innovation, by facilitating the physical mobility of people and exchanges of information and knowledge, locally and internationally. In many developing countries with inadequate infrastructure, policies target the provision of specialized infrastructure supporting productive capacity in selected geographical locations through the development of various types of industrial estates, such as cluster industrial parks, special economic zones and science and technology parks, often including accelerators and business incubators (as discussed in chapter IV) (UNCTAD, 2015b). Different elements of technical infrastructure are functionally connected, and synergies between them can provide a strong boost to local development. For example, adequate transport infrastructure allows easier transportation of windmill components to wind farms in remote locations, while reliable ICT infrastructure provides a channel for information and knowledge on their installation, management and maintenance in specific contexts.

**ICT** is now considered part of a country's critical infrastructure. The digital infrastructure is rapidly becoming a central element of the ICT infrastructure (UNCTAD, 2017a). As an enabling technology, ICT creates synergies with other key technologies such as biotechnology, nanotechnology and advanced manufacturing. ICTs have the potential to contribute to the social, economic and environmental dimensions of sustainable development, and are relevant to virtually all the Sustainable Development Goals. Taking advantage of this potential requires investments in basic ICT infrastructure, a reliable energy supply and telecommunication infrastructure, and regulation that ensures a competitive marketplace providing quality, affordability and accessibility. Ensuring affordable access to ICT and overcoming geographical, gender, generational and income digital divides are crucial, also helping to avoid new divides in access to, and capacity to benefit from, emerging digital technologies.

## 4. Financing innovation

Public intervention to support innovation, including through financial support, can be justified by various types of failure that actors would be unable or unlikely to solve without intervention, including systemic failures (such as lack of capabilities, institutional deficiencies or network failures) and market failures (such as asymmetries of information or the existence of knowledge spillovers). The fundamental challenges of financing of R&D (which is only a part of financing of innovation) in this respect are firmly established in both theory and practice (Akerlof, 1970; Spence, 1973; Stiglitz and Weiss, 1981; Arrow, 1974). The inability of private firms to appropriate new knowledge fully means that private rates of return to R&D are lower than social rates of return (Hall et al., 2009), leading to inadequate investment in R&D, development and adoption of new technologies, and innovation more broadly. Investment in R&D is particularly low in developing countries, especially LDCs (UNCTAD, 2007, 2013). UNCTAD's STI Policy Reviews have also highlighted the role of financial constraints in poor implementation of STI policies in many developing countries that have them.

Access to affordable financing is a major and longstanding obstacle to innovation by firms and a fundamental development constraint in many developing countries, particularly LDCs. Constraints on private sector financing for small firms and new technology-based firms are problematic even in developed countries, where small firms and start-ups in R&D-intensive industries face a higher cost of capital than larger and non-R&D-intensive firms (Hall and Lerner, 2010), and young and high-tech firms face greater difficulty in accessing credit markets (Lerner, 2002). Constraints on private sector financing for start-ups, SMEs and innovation in OECD countries have become tighter since the 2008–2009 global financial and economic crisis (OECD, 2015b; Wilson and Silva, 2013; Wilson, 2015).

Traditional financial systems have proved poorly suited to meeting the needs of innovation. In many developing countries, financial systems are characterized by excess liquidity in banking markets, which is not channelled into investment in technology and innovation due to a combination of risk-aversion, asymmetric information and the fundamental problem of pricing under uncertainty. There is also growing recognition among policy-makers globally of the overreliance of small firms on commercial bank financing (OECD, 2015b). In some developing countries, firms have relied on internally generated funds, establishing a dynamic profit–investment nexus, and financing new investment through reinvested profits (UNCTAD, 2004, 2006). This reliance creates a bottleneck for investment in innovative activities.

The financing gap is typically worst in the earliest stages of technology development and innovation, where uncertainty is greatest, limiting support from financial markets. Apart from personal savings, friends and partners, the main sources of risk finance at this stage are seed finance; technology, innovation and co-financing funds; early-stage venture capital; and business angels (chapter IV). This phase has been dubbed the “valley of death”, due to the high risk of innovation processes being forestalled by lack of financing. This is particularly problematic for new firms, as financing often becomes less of a bottleneck as enterprises mature. This pattern, well established in developed countries, also appears to hold in developing countries.

The shortcomings of private finance in funding innovation have led to governments becoming involved in financing R&D, technology and innovation in most countries to help fill the gap. Such involvement includes both direct financial support and indirect support mechanisms such as fiscal incentives, to encourage investment where private investors are unwilling to bear the risks involved (Mazzucato, 2013).

Tax incentives are used extensively to encourage investment in R&D and innovation in most OECD member countries, as well as in a number of developing countries, typically taking the form of reductions in the amount of corporate taxes to be paid through the granting of credits, deductions or deferrals (Villarreal, 2014). As a response to the divergence between private and social returns to innovation, tax incentives have the advantage of being market-based and entailing relatively limited administrative costs. However, their fiscal cost cannot be determined beforehand, as uptake depends on firm-level decisions.

Though a generic policy tool, tax incentives nonetheless allow some flexibility in terms of their focus and design, which differ considerably between countries. Tax incentives may target certain types of firms, sectors or activities to achieve particular policy aims, with many countries offering incentives to SMEs or “young” enterprises, or to priority sectors (e.g. energy) or regions. They may also be directed to particular activities, such as collaboration between academia and industry or the subcontracting of R&D activities by firms to encourage knowledge-based collaborative linkages.

Empirical studies in developed countries suggest that the effects of R&D tax incentives vary, both across subgroups of firms and between countries, rendering general conclusions difficult (CPB, 2014). However, the majority of such studies conclude that tax incentives are an effective means of stimulating private investment in R&D activities (OECD, 2011; CPB, 2014).

Even with tax incentives, successful innovation systems require a combination of public finance and development bank funding with private capital, market-based solutions and philanthropic financing (UNCTAD, 2014a). Governments need to play a substantial direct role in supporting the development and diffusion of the types of technologies and innovation that will bring large returns for sustainable development. However, public financing alone is insufficient, making the harnessing of private financing equally important. As recognized in the Addis Ababa Action Agenda of the Third International Conference on Financing for Development, this requires the use of innovative mechanisms and partnerships as well as traditional approaches (United Nations, 2015).

An important objective of STI policy is to promote the development of financing instruments appropriate to each stage of the innovation process, taking into account the financing gaps at each stage and the degree of financial development of the economy. Particular attention is required to surmounting the "valley of death" in early-stage of innovation financing, notably in terms of seed financing for the initial R&D needed to establish the technical feasibility and market potential of an innovation before the start-up phase.

Government grants represent an important source of seed capital for new firms. One useful approach is matching grants, providing financing to match spending by the enterprise itself, to share risks while limiting moral hazard effects that might otherwise encourage excessive risk-taking by the firm.

Box 3.1 outlines key policy lessons on financing innovation based on UNCTAD's technical cooperation with developing countries on STI policy.

Development banks represent a potentially valuable mechanism for financing innovation, providing loans or guarantees for new firms and innovative activities, either directly or through private financial intermediaries. They pursue developmental, rather than purely commercial, objectives, are responsive to horizontal and vertical industrial policies, and can take long-term investment positions and provide subsidized financing for developmental projects. This makes them well suited to financing projects that are conducive to development but entail risks that private sector investors are unwilling to assume. The ability of State-owned development banks to invest for the long term as "patient capital"

**Box 3.1 Policy lessons on the financing of innovation from UNCTAD technical cooperation**

Overcoming critical gaps in innovation financing is a key priority for developing country policymakers. It is important to avoid an excessive focus on financing research alone, particularly for countries at early stages of development, as applied research, design and product development often also require financing. Financial support for the adoption of new technologies also requires attention, as do technology extension services and training oriented towards incremental productivity improvements in SMEs.

Different instruments may be better suited to different stages of innovation and firm development, and in different national contexts, and a mix of instruments is likely to be required, rather than reliance on any single policy measure. Establishing seed capital grants, for example, does not preclude the simultaneous establishment of innovation funds or the implementation of other measures. There are also complementarities between promotion of venture capital and business angel finance and enabling firms to list on stock exchanges by developing domestic exchanges or ensuring access to foreign exchanges.

The "valley of death" in financing early-stage innovation is a universal challenge. In addressing this, it is important to recognize the risks inherent in innovation finance: unless the expectation of a high failure rate among projects is built in, excessive risk aversion in financing decisions will merely replicate the shortcomings of traditional financial institutions.

In all countries, it is good practice to seek to ensure additionality of public investment in innovation (crowding in) rather than crowding out private investment spending. Harnessing private sector expertise and promoting financing for promising new and high-growth firms are promising approaches. It may be appropriate to target innovation by both SMEs and large firms, particularly in the use of R&D tax incentives.

While consideration of financing issues is essential to improving innovation performance, complementary measures are also needed to amplify the impact of actions on financing – for example, to strengthen the entrepreneurial base, and thus establish a critical mass of good ideas and promising projects for investment.

In countries with limited experience of innovation financing schemes, there is a need to build institutional capacity for programme design, implementation, measurement, and monitoring and evaluation (M&E). Technical cooperation, both with countries that have greater experience and with international organizations, can play a useful role.

In countries facing tight financial constraints, financing programmes and innovation policy implementation more widely can be undermined by lack of fiscal space. Developing sources of funding for innovation financing and policy programmes may be essential. The use of natural resource royalties in Chile and Colombia provides an interesting example for other commodity-dependent developing countries. In Chile, royalties from copper mining are allocated to an Innovation for Competitiveness Fund in a proportion that is decided every year as part of the budget negotiation. On average, between 2013 and 2015 those funds amounted to 0.1 per cent of GDP. In the case of Colombia, 10 per cent of the royalties collected from hydrocarbons, metals and other minerals are allocated to the Science, Technology and Innovation Fund. Between 2013 and 2015 these resources represented an average of 0.39 per cent of GDP (Iizuka, Vargas & Baumann, 2017).

*Source:* UNCTAD secretariat.

arguably makes them superior to both venture capital and commercial bank loans as a source of financing to foster innovation (Mazzucato, 2013). The role of development banks in financing innovation varies greatly among countries, in some cases co-evolving with domestic financial markets and development strategies.

Development banks also provide a means of shaping markets in priority areas for sustainable development. The riskiest stages in the development of clean energy technologies, for example, have been financed mainly by public funds (Ghosh and Nanda, 2010). There is a strong argument that the major changes in energy technologies necessary for low-carbon development require strong mission-oriented support, for which development banks provide a useful instrument (OECD, 2017a). Development banks are among the largest issuers of green bonds to finance low-carbon energy projects (OECD, 2017b).

Brazil's National Development Bank is a leading example of a developing country development bank that has invested actively in clean technology and biotechnology. In 2010, its return on capital was 21 per cent, most of which was reinvested in new sectors, focusing on the "valley of death" in biotechnology. It is also a major financier of innovation through credit, venture capital/private capital schemes and non-repayable funding (Rubianes, 2014). The China Development Bank provides financing for foreign buyers of the products of Chinese firms (for example, for wind farms that use wind turbines manufactured in China) as well as for the firms themselves (Chopra, 2015).

## 5. Patent protection and incentives for innovation and investment

An important issue in harnessing STI for development is that of intellectual property (IP) transactions – the purchase, sale, assignment and licensing of intellectual property rights (IPRs).[48] As the principal form of IPR associated with technical innovation, patents are of particular importance in the present context.

The common rationale for the patent system is to provide incentives for innovation. In the pre-TRIPS era, so-called *technology-borrowers*, e.g. in South-East Asia and Brazil, successfully built up their technological absorptive capacities with relatively weak IP protection, while countries with higher standards of protection, notably in Africa, have performed poorly (Correa, 2005). However, such positive country experiences may be difficult to replicate due to subsequent changes in the legal and commercial environment within which developing countries operate.

IP protection in many developing countries has increased further in the two decades since the World Trade Organization Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS Agreement), as attention has shifted from the multilateral level to regional and bilateral agreements. Free trade agreements (FTAs) and bilateral investment treaties often include "TRIPS-plus" provisions obliging signatories to implement standards of IP protection and enforcement that go beyond their obligations under the TRIPS Agreement. Common provisions include limiting the use of TRIPS flexibilities, such as compulsory licenses and extending the term of patent protection beyond the 20-year minimum.[49]

Evidence suggests that stronger IP protection established under international treaties does not necessarily lead to better development outcomes in terms of local innovation and technology transfer.[50] In general, strengthening patent laws has led to increased patenting by foreign rather than domestic entities (Lerner, 2002). In most developing countries, the vast majority of patent applications are filed by non-residents (figure 3.2), potentially limiting the scope for local innovation in the technological areas concerned. Non-resident patent applications tripled from 264,196 in 1994 to 793,637 in 2014.

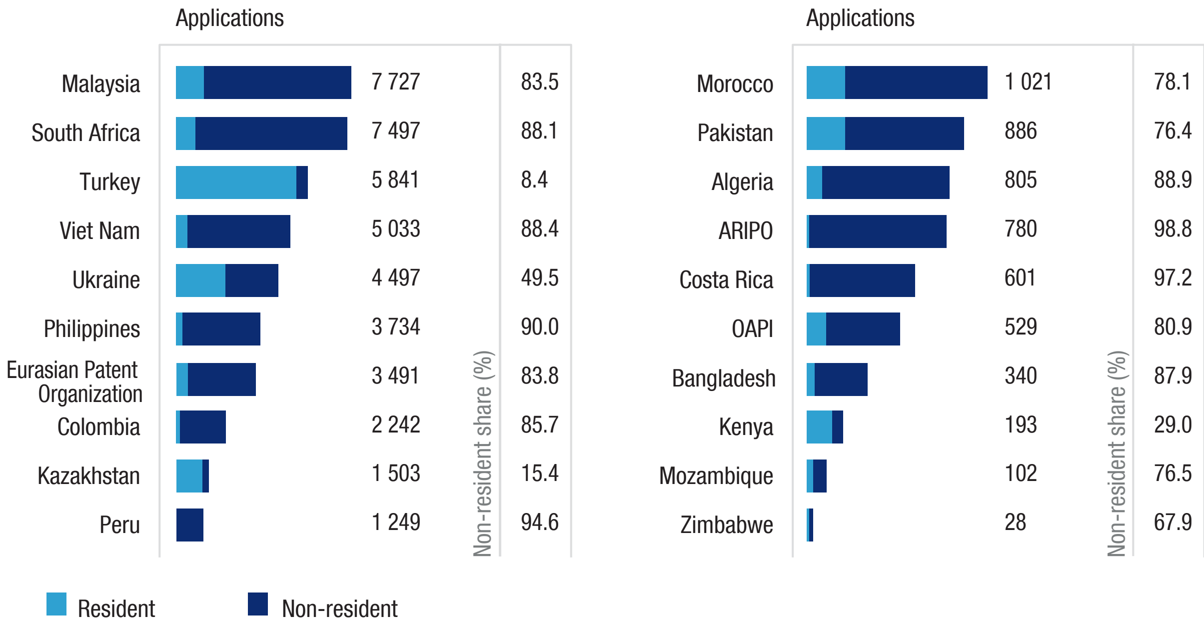
The primary obstacle to local innovation in developing countries and LDCs is not inadequate IPR protection, but lack of capabilities. The creation of low-cost research activities is therefore a higher priority to stimulate the knowledge economy (Blakeney and Mengiste, 2011). Since the TRIPS Agreement does not provide any binding minimum standards, developing countries with the capacity for incremental innovations might benefit from a utility model or "petty patent" system, granting less stringent protection to useful

48 Intellectual property rights are the rights given to persons over the creations of their minds (e.g. patents, trademarks, copyright, etc.), which usually give the creator an exclusive right to the use of such creations for a specified period. Available at www.wto.org/english/tratop_e/trips_e/intel1_e.htm (accessed 22 March 2018).

49 See, for example, Articles. 4.20 and 4.23 of the US-United States of America–Jordan free trade agreement.

50 The hiatus in negotiations on further harmonization initiatives, such as the proposed Substantive Patent Law Treaty at WIPO, can be largely attributed to the concerns of developing countries.

**Figure 3.2 Patent applications in selected low- and middle-income countries**




*Source:* WIPO Statistics Database, October 2016.

but relatively unsophisticated innovations that do not meet the eligibility standards for patent protection (Foray, 2007; UNCTAD, 2015a). Such systems also offer faster and cheaper registration.[51]

Strengthening IPRs globally was intended to encourage technology transfer to developing countries, particularly LDCs,[52] but unresolved issues remain regarding the effectiveness of the international IP regime in this respect (UNCTAD, 2016: chapter 3). While some studies (e.g. Maskus, 2004) have suggested that robust IP systems may facilitate the flow of technology through direct investment and licensing, the extent of any resulting increase in technology flows depends on the state of access to technological information (Maskus, 2004; Maskus et al., 2005). IPRs facilitate technology transfer only as part of the wider indigenous innovation system, in conjunction with industrial policy, forward and backward linkages, skilled personnel and STI and competition policies (Dhar and Joseph, 2012).

Technology transfer remains a key development dimension of any international discussions and processes related to IPRs (UNCTAD, 2014b, chapter 3). In principle, the TRIPS Agreement includes some provisions for flexibility in this regard. Article 7 of the TRIPS Agreement notes that IPRs should contribute to the "transfer and dissemination of technology… in a manner conducive to social and economic welfare, and to a balance of rights and obligations". Article 8.2 recognizes that countries may wish to prevent "practices which unreasonably restrain trade or adversely affect the international transfer of technology". And article 66.2 states that "Developed Country Members shall provide incentives to enterprises and institutions in their territories for the purpose of promoting and encouraging technology transfer to least-developed country members in order to enable them to create a sound and viable technological base".

However, translating such statements into policy practice changing the technological situation in developing countries has proved challenging. The very notion of technology transfer has been a fundamental point of contention, and can be interpreted in various ways, from transfer of codified technology (e.g. machinery and equipment, products and processes), tacit knowledge and know-how, to vocational training

[51] Protecting Innovations by Utility Models: What is a Utility Model? Available at www.wipo.int/sme/en/ip_business/utility_models/utility_models.htm (accessed 22 March 2018).

[52] Art. 66.2 of the WTO TRIPS Agreement, 15 April 1994. Available at www.wto.org/english/docs_e/legal_e/27-trips.pdf (accessed 22 March 2018).

and educational activities. Another important issue is the absence of any operative institutional apparatus that could help LDCs to realize the objective of article 66.2, in particular (UNCTAD, 2014b).

The rationale for strengthening the protection of IPRs has been questioned from a sustainable development perspective, and reforming the patent system appears increasingly desirable. The growth in patenting activity globally – particularly in new technologies such as ICTs, biotechnology and artificial intelligence – has increased the strain on the limited administrative capacities of patent offices in many developing countries, raising concerns about the viability of patent evaluations. It has also raised doubts about the extent to which the incentive structures that encourage patenting behaviour encourage wider innovation (Wagner, 2009). Particular concerns are the systematic use of patents to deter market rivals, the accrual of rents through monopolies and quasi-monopolies, and that the emergence of "patent trolls" risks dislocating entire groups of economic actors, such as small farmers, without contributing to technological innovation (UNCTAD, 2017b; Merges, 2009).

Building the capacity of developing countries and LDCs to foster innovation, absorb technologies and leverage the IPR system is a key issue. The experiences of several LDCs highlight the need for a more strategic approach, in order to boost absorptive capacities and harness intellectual property to promote radical innovation and technological leapfrogging (UNCTAD, 2012, 2015a; UNECA et al., 2016). However, technological learning and innovation need to be appropriate to each country's level of technological development, its economic structure and the capabilities of its public institutions and private sector (UNCTAD, 2007). Allowing them policy space to tailor IP laws in line with their national innovation strategies may also promote better use of IPRs for sustainable development in the long term. Historical development experiences highlight the desirability of IPR regimes that limit the scope of patent protection and other IPRs (to the extent possible within countries' international obligations) during the early stages of industrial development. This can be done, to a limited extent, by operationalizing the flexibilities allowed by the TRIPS Agreement (UNCTAD, 2015a). The 2030 Agenda for Sustainable Development raises further issues in terms of the orientation of IPR systems towards the needs of sustainable and inclusive development, as discussed in section C below.

## B. POLICY COHERENCE: INTEGRATING STI POLICIES IN DEVELOPMENT STRATEGIES

### 1. Aligning STI policy with national development plans

STI policies play an important role in promoting growth, employment and productivity, by fostering an effective innovation system and helping to overcome the market and systemic failures that inhibit innovation. Key objectives are to build up the innovation capabilities of firms and research and education systems, to stimulate innovation collaborations, to improve the enabling environment for innovation, and to ensure adequate financing for innovation. Major lessons from UNCTAD's considerable experience of STI policy support in developing countries are outlined in box 3.2.

Harnessing innovation effectively for development requires an integrated package of STI, industrial and trade policies directed towards building local capabilities and allowing them to be exploited competitively (Metcalfe and Ramlogan, 2008). This requires effective integration of STI policies in overall development strategies in support of development goals.

To be fully effective, STI policies need to be fully aligned with national development plans, to ensure coherence and synergies between the two. This requires consideration of the wider objectives of the development strategy throughout the policy process, from the initial vision to policy evaluation, and a systemic and integrated approach to the design, implementation and evaluation of STI instruments and policies.

**Policy coherence** entails "ensuring the systematic promotion of mutually reinforcing action, by the concerned government and non-government players, in order to create and maintain synergies towards achieving the defined objective" (OECD, 2003:2). This encompasses **policy consistency** (ensuring that individual policies are not internally contradictory); and **policy coordination** (ensuring that the various institutional and managerial systems that formulate policy work together effectively).

There are three types of policy coherence (OECD, 2003). **Horizontal coherence** entails ensuring the mutual consistency and reinforcement of the objectives and policy instruments of different entities. This means

**Box 3.2 Key lessons from UNCTAD's work on STI policies for development**

*STI policy challenges in emerging innovation systems*

While STI policy remains highly context-specific, policy-makers in developing countries face similar market and system failures. STI policy instruments need to be adapted to the structure of developing economies, often dominated by micro and small enterprises and the informal sector, while the majority of firms and innovation actors have limited absorptive capacities. STI policy should gradually build local capacity to learn and adopt new technologies; invest in R&D, training and innovation; and introduce major technological innovations. To build productive capacity and foster technological upgrading, STI policy needs, first and foremost, to support basic absorptive capacity and incremental innovation in traditional sectors.

Emerging innovation systems are fragmented, with only limited innovation collaboration among firms and between industry and research institutions, while investment in R&D and innovation is generally limited in both the private and public sectors. Scaling up investment in STI capacity will require significant external financial support, especially in the LDCs. Governance challenges are common, with inadequate coordination, short time horizons and a lack of sustained policy support. There is a great need for innovation support with a focus on longer-term development goals rather than only on short-term deliverables. Finding effective institutional frameworks for STI management is a priority.

*Building STI policy capacity in developing countries*

STI is not always a priority policy area in developing countries, and not all have an explicit STI strategy or policy. Building foundations for effective STI policy requires:

(a) **Assuming a systemic approach to STI policy**: Many developing countries rely on a linear science-push model of innovation, which does not fully harness the potential benefits of technology adoption and entrepreneurship. STI policy needs to be underpinned by a better understanding of innovation systems, to target the main market and system failures challenging innovation.

(b) **A broad definition of innovation**: Many developing countries focus too narrowly on technological innovation. Innovation needs to be understood broadly as including new products and services, processes, organizational improvements and business models, as well as other forms of innovation, including social, pro-poor and frugal innovation.

(c) **Effective priority setting**: Many countries have difficulties in establishing STI priorities and identifying where potential returns to the use of public resources in STI are greatest. This often results in long lists of "priority actions" that spread resources too thinly, making it difficult to accumulate critical mass and undermining the overall credibility of STI policy. This fragmentation, coupled with inadequate funding, limits the contribution of STI policy to development.

(d) **Mainstreaming and integration of STI policies**: Improving policy coordination across ministries and between government and other stakeholders is critical to improve innovation performance. Building strategic links and coordination between STI policy and other development policies (notably industrial policy, FDI, trade, competition, education and training, entrepreneurship and SME policies) is critical to harnessing the development potential of innovation.

(e) **Improved policy-making and implementation capacity**: This includes improving overall policy capacity throughout the policy cycle, from design through implementation, to monitoring and evaluation of STI instruments and portfolios. Some policy instruments are hardly used in developing countries (e.g. innovation funds or technology foresight), while others require greater managerial capacity (e.g. IPR).

UNCTAD's advice on STI policy has helped to raise awareness and systemic understanding of innovation among policymakers, and promoted STI policy mainstreaming across various development policy areas. Nonetheless, challenges remain in improving the design and implementation of STI policy and in seeking synergies between STI and long-term development goals. (Padilla-Pérez and Gaudin (2010) provide an analysis of common causes of STI policy failure in developing countries.) Fostering such synergies requires buy-in from diverse stakeholders, notably from politicians and top-level policymakers.

*Source:* UNCTAD secretariat.

strengthening the inter-connectedness of policies and promoting a "whole-of-government" perspective, by developing mandates and mechanisms that facilitate cooperation across ministries and departments in different areas of policy, and through cooperation with legislative bodies responsible for regulatory frameworks. Adequate coherence is needed across key policy areas, including industrial policies and those on STI, FDI, trade, education and competition, along with macroeconomic and exchange rate policies. (UNCTAD, 2014a, 2006)

**Vertical coherence** entails ensuring that the practices of agencies, authorities and autonomous bodies, as well as the behaviour of subnational levels of government, are mutually reinforcing with overall policy commitments (OECD, (2003):10). This is essential to effective policy implementation. It can be promoted through application of the subsidiarity principle – the design and deployment of strategies and policy instruments at the most appropriate level (Reid and Miedzinski, 2008). "Programme efficiency" is one way of stressing the need for vertical coherence, and the issue of ensuring compliance across levels of government is a typical expression of this dimension.

**Temporal coherence** entails ensuring that policies continue to be effective over time. This includes ensuring that short-term decisions do not undermine progress towards longer-term objectives, that future costs are taken into account in policymaking, and that the effectiveness of policies is not compromised by their interaction with other policies or other forces in society. This is one of the most challenging dimensions of STI policy, requiring dedicated impact studies.

Ensuring policy coherence requires **political leadership** to ensure a **long-term perspective**, and commitment to **regular evaluation**. **Stakeholder involvement** at the national, regional and local levels is particularly useful, to ensure that social and environmental impacts of policy are fully considered. Coherence also **requires advanced capabilities in policy design and implementation** that are often lacking in developing countries. This is a priority area for capacity-building, requiring innovative mechanisms from governments.

## 2. Steps towards building synergies between STI policy and national development plans

Though challenging, building a coherent policy mix merits a patient and sustained effort. This subsection proposes practical steps that developing country governments can take to exploit the developmental potential of STI policy.

### *a. Conduct a critical review of the innovation system and STI policy*

A systemic approach to STI requires a solid understanding of innovation system performance among policymakers, including knowledge of systemic bottlenecks in all its dimensions. In developing countries with limited experience of STI policy, a useful starting point is a comprehensive policy review to assess existing innovation potential and the STI policy mix, including a cross-impact assessment of existing policy instruments. By providing knowledge of current STI policy coverage, gaps and overlaps, and of causal relationships and conflicts between different instruments, such a review can provide a foundation for evidence-based policy design, coordination and improved policy coherence. The process of conducting a comprehensive STI policy review is also an important part of policy learning, which is a key aspect of building policy capacity.

### *b. Build a shared vision and choose strategic priority areas for STI policy*

A sustainable innovation policy requires a long-term vision to provide the framework and direction for short-term goals. Building a shared vision and choosing strategic priorities through a participatory policy learning process help to reduce the perceived uncertainty and complexity of policy choices, and to pre-empt possible contestation of the selected course of action.

Given the political nature of priority-setting processes, key stakeholders should be actively engaged in the development of a vision and in deliberations on STI priorities. The process should be based on a critical assessment of where STI can contribute most to the country's key development objectives, considering the likely economic, social and environmental impacts of innovation, and should be accompanied by dedicated impact assessments of alternative options. Priority-setting should seek to ensure an equitable distribution between communities and localities of the risks and benefits of the selected innovation pathways (Altenburg and Pegels, 2012; Weber and Rohracher, 2012). It should also take into account existing policy mandates and capabilities to address selected challenges systematically. As discussed in chapter IV, the smart specialization approach can be a useful approach to the selection of priorities for policy intervention.

### c. *Facilitate strategic partnerships*

Political leadership and strategic partnerships are fundamental to effective STI policy and governance (see box 3.3). The vision and strategic priorities for STI should be supported by established and new partnerships involving key stakeholders for the selected areas, including both established and emerging actors. Building partnerships around specific priorities from the outset of strategy formulation is essential, to ensure a sense of ownership and commitment among key actors, and can contribute to building new networks of actors mobilized around societal challenges. Building such partnerships and fostering innovation in support of sustainable development in priority areas require political commitment and leadership and actions by public and private actors, including different ministries. Collaboration skills are essential, among both policymakers and other actors in the system.

**Box 3.3 Finland's Research and Innovation Council – Leadership and coordination of key stakeholders in innovation policy design, and well-developed M&E practices**

The Research and Innovation Council of Finland is a powerful multi-stakeholder STI policy coordination mechanism, which has contributed to the country's consistent rating as highly innovative in international rankings. The Council is chaired by the Prime Minister, and includes ministerial-level representation of key government ministries, including Education, Industry, Trade, Science and Finance. High-level representatives of the science community, the private sector, trade unions and civil society also participate. The Council meets twice a month to discuss strategic issues, budget allocations and institutional topics.

The Council played an important role in the design of Finland's development strategy, integrating STI into its central focus. It combined political leadership at the highest level with broadly based representation of important national actors to establish a consensus on economic strategy, which was essential to the design of a coherent national strategy based on developing innovation capacity. This leadership was critical to establishing a coherent and coordinated basis for STI and other policies to respond to and overcome the national economic crisis of the early 1990s. Implementation challenges have been addressed through careful design, measurement and M&E, and through representation of all key actors in the Council, which promotes coordination and buy-in by these key stakeholders.

There is a culture of policy learning within various layers of Finnish policy-making, commonly based on periodic evaluations of institutions and programmes. The Finnish experience demonstrates the time needed to develop an open evaluation culture: evaluations started slowly in the 1970s, only becoming institutionalized in the 2010s. Policy learning in Finland is largely based on drawing lessons from evaluations of its own institutions, together with benchmarking through searching for best practices around the world.

Finland has also institutionalized foresight initiatives involving various stakeholders. Once during each electoral period, the Government submits to Parliament a report on the future, focusing on long-term perspectives. Each report is restricted to key strategic issues related to policy decisions to be taken in a 10–20 year period, and aims to encourage broad debate in society. The Parliament of Finland itself has had a standing Committee for the Future since 1993, consisting of 17 Members of Parliament, which serves as a think tank for futures, science and technology policy.

The Finnish experience of monitoring and evaluation suggests two overarching lessons. First, impartial evaluations of institutions, policies, instruments and programmes are an important means of providing valuable lessons and improving transparency, particularly if published. Second, policy learning can be complemented by building evaluation into institutional governance mechanisms and facilitating the flow of ideas from international organizations.

*Source:* UNCTAD secretariat, based partly on Halme et al. (2014).

### d. *Design a long-term STI strategy and policy road map*

The overall vision and priority actions in selected areas can be operationalized through national STI strategies and policy road maps. An **STI strategy** identifies policy objectives and ensures that STI policy is aligned with the overarching objectives of the national development plan. It should include an indication of the STI policy mix, encompassing policy objectives and instruments in relevant policy areas and mechanisms relevant to policy implementation and coordination.

An **STI policy road map** is a strategic tool integrating various policy strategies and instruments into a single strategic document and process, as a tool to support analysis and policy coherence. It lists the key instruments, indicates their intended and expected effects over time, and analyses the interaction of the effects of different policies and their relationship with external trends. The STI strategy and road map should include a **dedicated M&E system** allowing progress towards the stated objectives to be measured. The policy road map is a continuing process, and should be updated as policies are implemented.

The experience of countries that have been successful in technological upgrading strongly supports the need for long-term strategic planning in developing countries. Building a well-functioning national innovation system requires long-term and patient policies. Countries such as China, the Republic of Korea and Singapore established the basics in an initial phase before moving on to more advanced learning and capability development. The Republic of Korea, for example, established the foundations for an innovation system between the early 1960s and the mid-1970s. It then implemented revised strategies in the late 1970s and the 1980s, allowing it to catch up exceptionally rapidly with more technologically advanced countries (Lee, 2016).

#### *e. Establish monitoring and evaluation systems and nourish policy learning*

Policymaking should be evidence-based, with M&E based on relevant metrics as an integral part of the policy process. This allows policies to be refined over time, according to their impact and changes in national and international circumstances (Dodgson and Bessant, 1996; Teubal, 1996).

Developing countries should first establish basic M&E capabilities and data infrastructure. Collecting relevant STI indicators regularly and building monitoring databases are key to improving policy implementation. Policy learning should be actively encouraged throughout the policy process, from vision-building to evaluation. This is an evaluative and reflective process, engaging key policy stakeholders to learn from evaluation and other relevant studies and processes as a basis for continuous improvement of policy design and implementation, and adaption to the changing local context.

Activities and instruments that developing country Governments might consider to foster learning and evidence-based policies include:

(a) STI policy reviews and strategic studies providing systemic overviews of the STI system and policy mix;

(b) M&E systems for STI policy, including policy, programme, project and institutional evaluations, and an integrated policy database of evidence on the effectiveness and efficiency of key STI instruments;

(c) Ex ante and ex post impact assessments analysing the potential and actual impacts of publicly supported innovations on development objectives;

(d) Prospective studies and foresight, including horizon-scanning;

(e) Policy benchmarking, comparing policy instruments and policy mixes with other countries addressing similar societal challenges;

(f) Capacity-building and training, focusing on the design, implementation and evaluation of STI policies and on institution-building;

(g) National and international policy dialogues and brokerage events, to extend policy learning to key stakeholders and relevant external actors, while recognizing that successful policies and instruments that have been successful to address a particular societal challenge may not be adequate in another system.

## C. REDIRECTING INNOVATION TOWARDS INCLUSIVENESS AND SUSTAINABILITY

### 1. STI policies for inclusiveness and sustainability

Addressing the challenges of inclusiveness and sustainability adds new priorities for STI policy, necessitating different policy approaches and new policy instruments. Defined only as a response to market and system failures limiting innovation, STI policy does not address the failure of market mechanisms to reward the social and environmental benefits of innovations or to penalize their social and environmental costs.

Orienting STI policy towards sustainable development thus requires broadening its strategic focus beyond purely economic concerns to integrate societal challenges at its core. This represents a substantial shift. As Foxon and Pearson (2008:150) observed a decade ago, "first, long-term social and environmental problems tend to receive relatively low priority in the face of more immediate policy pressures; second, the interrelated nature of these problems and radical uncertainty in future costs and benefits of complexity are not easy to address within current process; and third, the goals and trajectories to ensure sustainability are inevitably contested".

A key goal of STI policy for the Sustainable Development Goals is thus to internalize the direct and indirect contributions of innovations to economic, social and environmental aspects of sustainable development. However, this alone is insufficient. For example, climate change cannot be tackled entirely by market-based instruments such as carbon pricing, emissions trading and support for technology development. Rather, it requires stringent targets that impose limits on production and consumption systems.

More generally, sustainable development requires fostering transformative innovations with the potential to supplant unsustainable practices and systems. This requires a portfolio of mutually reinforcing policy instruments, exploiting synergies between policies in STI and in other areas, ensuring that public interventions support innovations that contribute to social inclusion and environmental sustainability, focusing on areas with little or no prospect of short-term financial returns. Developing capacity in technology foresight (e.g. horizon scanning and ex ante impact assessments) can help, by allowing countries to identify and exploit the potential of frontier technologies for sustainable development, to identify priority technologies in the short, medium and longer term, and to assess the potential effects of emerging technologies. There are also important implications for the methodologies and types of evidence needed to support policy design and implementation, for example combining methodologies and data for technological, economic, social and environmental impacts in assessment of the environmental impacts of innovation.

UNCTAD and the United Nations Commission on Science and Technology for Development have formulated a number of policy recommendations for developing countries to systematize foresight exercises as standard practice in their technology policy and to leverage foresight in specific priority applications (for example, digital technologies).[53] The Commission could support developing countries in this field by facilitating networking and partnerships among technology foresight organizations, and by conducting international technology assessments and foresight exercises on frontier technologies and their implications for the Sustainable Development Goals.

Table 3.1 provides an overview of STI instruments and their potential roles in fostering innovation for sustainable development.

[53] See, for example, Economic and Social Council (2016). Foresight for digital development: Report of the Secretary-General. E/CN.16/2016/3. Geneva. 29 February; and Economic and Social Council (2016). Strategic foresight for the post-2015 development agenda: Report of the Secretary-General. Geneva. 23 February.

**Table 3.1 Policy instruments to foster innovation for sustainable development**

| | Policy instruments | How can they support innovation for sustainable development? |
|---|---|---|
| Regulations and standards | Environmental and health protection regulations | Provide incentives to innovate to comply with regulatory frameworks (e.g. substitution of harmful chemicals) and disincentives to free-riding by introducing penalties. |
| | Product and industrial process standardization | Provide incentives to innovate to comply with environmental and social performance standards for products and processes |
| | Labels and certification | Promote innovative products and processes by providing customers with information on environmental and social performance of products and services |
| | Intellectual property rights | Encourage firms to engage in innovation activity by protecting their knowledge; and open access to knowledge and technologies contributing to sustainable development |
| Economic and financial instruments | R&D funding | Provide direct support for R&D underpinning sustainable innovation |
| | Innovation funding for companies | Provide direct support for innovation activities in the areas relevant to sustainable development |
| | Equity support to venture and seed capital | Provide equity dedicated to eco-innovation and de-risk eco-innovation investments |
| | Feed-in tariffs and similar subsidy schemes | Provide financial incentives to adopt and diffuse innovative technologies in selected technology areas (e.g. renewable energy) |
| | Tradable permit systems (e.g. emissions trading) | Allocate or sell emission rights to polluters that can be traded and create incentives for innovation through pricing of emission rights and the prospect of their reduction. |
| | Removal of subsidies for unsustainable activities | Removes market distortions that inhibit sustainable innovation (e.g. subsidies for fossil fuels) |

**Table 3.1 Policy instruments to foster innovation for sustainable development (cont'd.)**

| | Policy instruments | How can they support innovation for sustainable development? |
|---|---|---|
| Fiscal instruments | Tax incentives for R&D for companies | Reduce taxation for companies undertaking R&D that underpins innovation |
| | Tax incentives for technology adopters | Reduce taxation for companies adopting innovations with environmental and social benefits |
| | Environmental taxation | Reduce taxation for companies undertaking R&D that underpins eco-innovation |
| | Removal of tax reliefs for unsustainable activities | Remove market distortions that inhibit sustainable innovation (e.g. subsidies for fossil fuels) |
| Demand support | Sustainable public procurement | Create markets for goods and services with positive impacts on local communities in areas relevant to sustainable development (e.g. Green Public Procurement) |
| | Pre-commercial (R&D and innovation) procurement | Create markets for innovative goods and services and stimulate experimentation with new applications of emerging technologies |
| | Support to private demand | Provide incentives (e.g. vouchers) for consumers to purchase innovative goods and services with demonstrated positive social and environmental impacts |
| Education & training | Adaptation of formal education curricula to address the Sustainable Development Goals | Tailor higher education and vocational training curricula to needs for sustainable development and provides qualified and skilled workforce (possibly in collaboration with industry and other organizations). |
| | Support to on-the-job training and learning organizations | Facilitate upgrading of skills, complementing formal training, and; may facilitate transmission of tacit knowledge |
| | Placement schemes and staff mobility | Support learning, knowledge exchange and connections between actors in the innovation system with a focus on actors active in promoting sustainable innovation |
| Regional innovation and networks | Clusters, industrial zones, and science and technology parks | Encourage smart specialization in innovation relevant to societal challenges in regions with high potential and/or goods and services with environmental and social benefits |
| | Technology platforms and networks | Promote sharing of information and knowledge-sharing on eco-innovation |
| | Road maps and foresight | Create shared vision, commitments and road maps for experimentation, investment and development of eco-innovation |
| Trade policy | Trade tariffs | Remove barriers to trade in innovative goods and services which contribute to the , Sustainable Development Goals; open access to knowledge important for adoption and diffusion of technology, also, impose barriers to environmentally and socially harmful goods and services |
| Capacity-building and information provision | Business advisory services | Promote skills and knowledge relevant to eco-innovation |
| | Local entrepreneurship and business incubation | Promote local entrepreneurship and innovation |
| | Technology transfer and matching | Promote identification and transfer of innovative technologies relevant to specific challenges |
| | Capacity-building for governments | Promote building of government capacity to design, implement, coordinate and evaluate STI policy to enhance its support for sustainable development |
| | Market intelligence services | Promote sharing of information, data and knowledge on innovation trends related to sustainable development and reduce information asymmetry |

*Source:* UNCTAD secretariat.

## 2. Intellectual property rights and the Sustainable Development Goals

As discussed in chapter I, many emerging technologies have the potential to make a major contribution towards achieving the Sustainable Development Goals across multiple areas. However, there are important areas of tension between these objectives and some aspects of current IPR protection arrangements. Realizing this potential will thus require harnessing IPRs to this end.

Furthermore, many of the proprietors of the intellectual property of frontier technologies are concentrated in the private sector of developed countries and some larger developing countries with greater technological capabilities. This raises further questions as to the potential for licensing in frontier technologies, reverse engineering and technology diffusion, given the limitations imposed by the TRIPS Agreement and the even higher standards established by some free trade agreements (Max Planck Institute, 2012; UNCTAD, 2015a).

For example, agriculture – central to Sustainable Development Goal 2, to "end hunger, achieve food security and improve nutrition and promote sustainable agriculture" – has become significantly technology-driven, and the application of IPRs associated with biotechnology has major implications for food security. The international IPR system for patenting seeds[54] also reinforces the concentration of the agricultural biotechnology sector in a few multinational enterprises, particularly in the seed sector, resulting in an oligopoly in the supply of inputs vital to food security (Blakeney, 2009).[55] Patents for many cutting-edge technologies are held by a handful of multinational enterprises, which thus control a vast proportion of the agricultural inputs market. The need for small-scale farmers to adopt new technologies to remain competitive in global value chains creates a state of dependency on these few companies for inputs, and may also give rise to production bottlenecks unless addressed by competition laws (Lianos et al., 2016; UNCTAD, 2008).

The patenting of genetic material and the assignment of plant variety rights have allowed plant materials to be commodified, impeding developing countries' efforts to leverage the international IPR system to address their concerns, not only in food security but also in biological diversity. In agriculture as in other areas, as discussed in chapter II, capabilities are an important constraint: many developing countries, particularly LDCs, lack both the scientific capability to innovate and patent new materials and the capacity to catalogue their biomaterial resources.

Many of the Sustainable Development Goals are affected by the Convention on Biological Diversity (CBD) and the ability to continue to use biological resources sustainably. The Convention reaffirms the sovereign right of States over genetic resources and seeks the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising from their utilization. It also requires the respect, preservation and maintenance of associated traditional knowledge at the national level. However, a policy gap remains in improving IP systems at the national and international levels to make use of existing or adapted IP and other tools to adhere to the objectives of the CBD and the Nagoya Protocol (UNCTAD, 2014c).

The most important interface between IP rights and biodiversity is the issue of access and benefit sharing (ABS). The inclusion of ABS as an objective of the CBD was based on the premise that biodiversity has been used by public institutions and private entities to produce new knowledge and products that have brought various benefits to their new users (such as new medicines, cosmetics or food products), but not necessarily to its original owners or custodians. Clear, fair and equitable rules on ABS are critical to prevent the misappropriation[56] of genetic resources and associated traditional knowledge, sometimes referred to as 'bio-piracy'. Genetic resources may be misappropriated through the IP system, for example when a company sources biological resources from a country without consent, utilizes that resource in R&D to develop an invention, and then attempts to patent that invention without any benefits to the provider, or without mentioning where the resource was obtained.

However, recent advances in digital technologies have led to convergence with wider technologies, such as those in the biomedical fields. Where bio-prospectors once needed to remove a plant or animal physically from its natural habitat, the organism can now be digitally scanned, and its genetic structure sequenced at the point of contact. This information can then be uploaded to the Internet and transferred to a DNA synthesiser for duplication or reconfiguration elsewhere – essentially creating "digital DNA". By allowing plants to be genetically engineered in laboratories, digital DNA and synthetic biology make it very difficult to trace genes back to their origins, allowing the objectives of the Nagoya Protocol to be circumvented (Bagley, 2015).

IPRs are also of major importance to Sustainable Development Goal 3, to "ensure healthy lives and promote well-being for all at all ages", most notably due to their implications for access to medicines.

54 Article 27.1 of the TRIPS Agreement obliges Member States to provide protection for plant varieties and make patent protection available for inventions in all fields of technology.

55 Recent mergers and acquisitions activity among multinational seed corporations further highlight the consolidation of the market for agricultural inputs, which is composed of a handful of global suppliers (African Centre for Biodiversity, 2017).

56 Narrowly defined, misappropriation refers to access to and use of genetic resources without prior informed consent and/or mutually agreed terms pursuant to the national access legislation of the country providing the genetic resources and applicable international rules on access and benefit sharing. This view is based on the definition proposed by Switzerland for WG-ABS 9 on 18 February 2010 regarding the need for definitions in the lead up to COP 10 at Nagoya, Japan.

Patent protection of pharmaceutical products was not mandatory prior to the WTO TRIPS Agreement, and its inclusion in the Agreement is one of its most controversial aspects. While the Doha Declaration on TRIPS and Public Health allowed some progress on the availability of affordable antiretroviral (ARV) medicines (UNAIDS, 2016),[57] major health challenges in developing countries in recent years have raised new issues. The Ebola and Zika virus outbreaks, for example, raised issues of access to patented genomic vaccines,[58] which are being developed in advanced economies. Other frontier technologies in the biomedical fields that are being developed in advanced economies are also raising important IPR issues. (See box 3.4).

There is some indication of the successful use of TRIPS flexibilities between 2001 and 2016, some governments having been able to use public non-commercial use licences and the LDC pharmaceutical transition measure to procure lower-priced generic medicines (World Health Organization, 2018), although the composition of developing countries and LDCs using these flexibilities remains unclear. Full utilization of such flexibilities would improve both the availability of medicines and local R&D and innovation in the pharmaceutical sector (UNCTAD, 2011) and beyond. However, this obstacle is compounded by TRIPS-plus provisions in many free trade agreements and bilateral investment treaties, such as extended patent protection periods for pharmaceuticals. Moreover, limited use of TRIPS flexibilities remains an obstacle in other areas of technology.

57 An amendment to art. 31bis of the TRIPS Agreement provides a solution to the para. 6 problem relating to the ability of developing countries' limited ability countries to make effective use of compulsory licenses, by allowing production and importation of patented medicines where manufacturingthe capacity does not exist. to manufacture. See Doha WTO Ministerial 2001: TRIPS WT/MIN (01)/DEC/2, 20 November 2001. Available at www.wto.org/english/thewto_e/minist_e/min01_e/mindecl_trips_e.htm (accessed 23 March 2018).

58 See World Economic Forum (2017).

**Box 3.4 Ownership dispute over CRISPR-Cas9 gene editing tool**

One of the frontier technologies generating particular attention in the biomedical fields is the CRISPR-Cas9 gene-editing tool, which has enormous potential to improve understanding of human and animal diseases and their treatment. It has the potential to revolutionize medicine and agricultural research, offering cures for genetic disorders and degenerative diseases by rewriting the genetic code of patients.

CRISPR (clustered regularly interspaced short palindromic repeats) is a natural defence mechanism that allows bacterial cells to detect and destroy the viruses that attack them. Widespread interest in the technology was first generated by publication of a scientific paper in June 2012 by Emmanuelle Charpentier now at the Max Planck Institute for Infection Biology, Germany and Umeå University, Sweden; and Jennifer Doudna of the University of California, Berkeley, United States. Their paper outlined how CRISPR, with the help of an enzyme called Cas9, could be transformed into a tool to edit genes. Their first CRISPR-related patent application was filed in May 2012 and is still under review.

Eight months later, in January 2013, scientists at the Broad Institute of the Massachusetts Institute of Technology and Harvard University, led by Feng Zhang, reported that they had found a way to use CRISPR-Cas9 to edit the cells of mammals, further fuelling interest in its potential to generate new and more effective medical treatments. The Broad researchers filed their first CRISPR-related patent application in December 2012 and requested a fast-track review process. The patent was granted in April 2014.

The grant of the patent to the Broad Institute sparked a high-stakes legal battle, as ownership of the commercial or IP rights to CRISPR-Cas9 could generate huge financial returns and allow the holder to decide who can use the technology.

On 12 February 2017, the Appeals Board of United States Patent and Trademarks Office ruled that the patent granted to the Broad Institute did not overlap or interfere with patent claims filed by the University of California, Berkeley team for the use of the system in any environment. This decision means that the Broad Institute will be able to keep its United States patents, which cover methods of using CRISPR-Cas9 in mammalian cells (eukaryotes), while the University of California, Berkeley can maintain its United States patent application, which claims methods of using CRISPR-Cas9 in any cells.

While this may be good for the two institutions, it creates uncertainty for the biotech business community, as it remains unclear whether they need to obtain licenses from both universities.

*Source:* WIPO Magazine, Issue 2, April 2017.

Technological solutions are also essential to Sustainable Development Goal 7, to "ensure access to affordable, reliable, sustainable and modern energy for all" and Sustainable Development Goal 13, to "take urgent action to combat climate change and its impacts". While IPRs can encourage innovation to provide technical solutions to tackle climate change and provide clean energy, they can be a barrier to technology transfer in some cases (de Coninck and Sagar, 2015). Patent protection of climate change mitigation technologies such as biofuels, solar thermal, solar photovoltaic (PV) and wind energy have increased significantly in recent years (Helm et al., 2014). Equally, the higher technical standards required for advanced biofuel production will ultimately be proprietary and costly to obtain, limiting transfer of the technology to developing countries (Juma and Bell, 2009). Achievement of Sustainable Development Goals 7 and 13 will therefore require greater clarity regarding IP transactions in the development and transfer of climate-friendly technologies within international forums on climate change.

Such linkages between IPRs and the Sustainable Development Goals suggest that an exclusive focus on increasing standards of IPR protection is not the optimal way forward. Rather, the 2030 Agenda for Sustainable Development further highlights the importance of recognizing the need for special and differential treatment for developing countries to facilitate sustainable development, especially in relation to the targets on technology and trade. This is a key aspect of Sustainable Development Goal 17, to "revitalize the global partnership for sustainable development".

Of paramount importance is the need to incorporate the principle of policy space for flexibility and inclusiveness in new international regimes. If they are to contribute to the 2030 Agenda for Sustainable Development, IPRs should be geared to each country's level of development and technological capacities, especially in LDCs, to maximize incentives for innovation to the extent possible within the policy space allowed under the TRIPS Agreement. This requires promotion of a competitive environment, including IP law and policy, that reflects an appropriate balance between the public and private dimensions of knowledge (UNCTAD, 2010), and between the granting of exclusive rights and the promotion of follow-on innovation by competitors. A regional approach to IP in relation to local production issues may foster regional innovation and R&D, particularly in the pharmaceuticals sector, to develop regional markets and economies of scale.

## 3. Technological change, employment and the social contract: Is this time different?

Numerous prominent people from the fields of academia, politics and technology have recently raised the issue of the implications of current and prospective changes in productive technologies, and particularly their potential effects on employment (as discussed in chapter I) for the social contract.[59]

Historically, the evolution of the concept of the social contract (from an economic perspective) has been closely connected with socioeconomic dislocations, particularly those arising from major technological changes, from agricultural mechanization through the industrial revolution. The widespread unemployment and increased inequality associated with the economic disruptions of the first half of the twentieth century, in particular, were an important driver of the materialization of the social contract in many developed countries in the form of the welfare state. However, the welfare state has come under increasing pressure since the late 1970s as a result of financial and political pressures; and it now faces fundamental challenges, not only from rapid technological change, but also from a wider context of globalization, asymmetries in the mobility of capital and (especially unskilled) labour, international migration, increasing inequality, demographic change and increasingly insecure labour markets (associated with the "gig economy").

Consideration of the implications of these changes for the social contract remains at an early stage,[60] but the challenges are clearly considerable. While many observers anticipate, extrapolating from past episodes of technological change, that there will be no net reduction in employment in the long term, this view is far from universal, and there are widespread concerns

59 Particularly notable examples include former United States President Barack Obama (Dadich, 2016), Facebook founder Mark Zuckerberg (2017) and Director of the London School of Economics Minouche Shafik (2017).

60 The London School of Economics, for example, has recently announced the launch of a major research programme entitled Beveridge 2.0 (commemorating the 75th anniversary of the 1943 Beveridge Report, which laid the foundations of the welfare state in the United Kingdom) to rethink the social contract for the twenty-first century.

that many people may become unemployable due to their inability to adapt their skills to the new environment (Pew Research Center, 2014). Moreover, these changes come at a time when unemployment and underemployment are already at high levels globally. Unless effective means can be found to ensure lifelong financial security and access to essential health care, independently from employment, and to counter increases in inequality, this could raise the risk of social and political disruption, as well as undermining economic sustainability (West, 2015).

Recent interventions on the theme of technological change and the social contract have included co-ownership by workers of infrastructural technologies, greater sharing of corporate profits, negative income taxes, shorter working hours to share the available work more widely, and credits for voluntary work. The following subsections discuss two themes that have been almost universal in discussions to date:

(a) Lifelong learning, to allow workers to adapt to rapidly changing demands in the labour market; and

(b) Universal basic income (UBI) – periodic cash payments made unconditionally to all members of society, without means-testing or work requirements – to provide financial security and support those unable to adapt successfully.

### *a. Lifelong learning policies*

Taking full advantage of new technologies requires ensuring that education remains ahead in the race against technology, by anticipating the effects of technological change on employment and ensuring the availability of the necessary skills (chapter II). Workers themselves also need to reskill constantly to remain employable in a context of rapidly changing skill requirements, changing occupations more often across longer working lives. This requires a constant and dynamic process of transformation through lifelong learning, in which the key competences are flexibility, adaptability and capacity to learn. The importance of lifelong learning is recognized explicitly in Sustainable Development Goal 4, to "ensure inclusive and quality education for all and promote lifelong learning".

As well as skills *upgrading*, this requires skills *updating*, to perform the non-routine manual and cognitive tasks left to humans as automation polarizes the labour market by displacing primarily middle-skilled workers. Such tasks include, in particular, manual tasks requiring flexibility, situational adaptability, judgment, visual and language recognition, in-person interaction, and "common-sense skills that we understand only tacitly", which are particularly challenging for automation (Autor, 2016:3, citing Polanyi).

Many workers do not have the capacity to pursue continuous education without support and guidance. It is noteworthy that participation in adult education and learning is greatest among adults who are highly educated and already employed (OECD, 2014). Moreover, private sector support is limited by lack of resources for training, particularly in SMEs, and the disincentives arising from high levels of staff mobility, which limit the ability of employers to appropriate the benefits of investments in human capital. Governments thus have a key role in investing in lifelong learning, particularly for those in the lower-skilled occupations most vulnerable to automation and other disadvantaged and vulnerable groups, by ensuring the availability of affordable and high-quality lifelong learning opportunities.

This means reforms to educational and training systems, both to provide children and young people with the skills needed to evolve with a continuously changing environment, and to promote retraining, skills upgrading and skills updating for adults. However, while some general patterns emerge, as discussed in chapter II, there is no one-size-fits-all approach. Rather, educational goals and pedagogical approaches need to be tailored to each country's particular circumstances, including its level of development and industrialization, its skills needs, and its education and training capabilities (UNIDO, 2013; World Bank, 2016).

Of particular importance to lifelong learning are technical and vocational education and training (TVET) and apprenticeships. Youth employment opportunities are better in countries with well-established and high-quality vocational and apprenticeship programmes (OECD, 2015a). Apprenticeships can be promoted through financial incentives (e.g. direct subsidies or tax benefits), redesign of apprenticeship schemes or improvements in employers' training capacity (Kuczera, 2017). Countries such as Benin, Brazil, Kenya and Ethiopia have apprenticeship schemes (Albaladejo and Weiss, 2017).

Strengthening of TVET programmes, which are often highly fragmented and uncoordinated, is a key element. Their effectiveness may be enhanced by appropriate involvement of the private sector, for example, through public–private partnerships. Financial incentives can come from international cooperation initiatives such as the Financing Facility for Skills Development under the Skills Initiative for Africa of the African Union and the German Federal Ministry for Economic Cooperation and Development, which supports TVET actors in selected pilot countries to strengthen skills development for young people. Successful TVET systems operate in India and Ethiopia, while Nigeria is in the process of revamping its TVET system to prepare for the impact of disrupting technologies (Olajide Olorunnisola, 2014). It is important that TVET systems address the needs of the most vulnerable parts of society, including youth and women. Viet Nam's gender-sensitive TVET policies, for example, have contributed to greater gender equality in education and employment (Albaladejo and Weiss, 2017).

As well as providing opportunities, governments need to ensure incentives for firms to support training and for employees to undertake training, including through financial support in the form of subsidies, tax rebates and credits, grants, loans, voucher systems, national training funds, etc. Singapore, for example, provides credits for lifelong learning, Ghana and Kenya operate targeted voucher schemes for vulnerable and poor population groups, while Brazil, Chile, Malaysia, Mexico, Nigeria, Peru, South Africa and Tunisia have national training funds financed from payroll taxes (World Bank, 2016; Albaladejo and Weiss, 2017).

Strengthening education and training for lifelong learning will require increased investment, particularly in developing countries. The International Commission on Financing Global Education Opportunity has called for an increase in total (public and private) annual education spending in low- and middle-income countries, from $1.2 trillion in 2016 to $3 trillion in 2030 (ICFGEO, 2016).

New technologies can make an important contribution to lifelong learning, through virtual or e-learning. Massive open online courses (MOOCs)[61] – providing online lectures, free or at low cost, and opportunities for online collaboration and interactive learning – have the potential to revolutionize the delivery of post-secondary education. Since MOOCs emerged in 2011, an estimated 58 million people have signed up for 6,850 courses from more than 700 universities worldwide, 23 million of them in 2016 alone – although growth has slowed as providers have become increasingly focused on monetization. A quarter of new users in 2016 came from regional providers, such as XuetangX (China) and Miríada X (Latin America). The top five providers by registered users were Coursera, edX, XuetangX, FutureLearn and Udacity (Class Central, 2016).

In principle, MOOCs can greatly reduce the cost of scaling up and widening access to higher education, including to marginalized and disadvantaged populations, those in remote and conflict-affected areas, displaced people and refugees. However, unless focused on those in greatest need, they may lead to increasing inequality. While participation from Asia, especially China and India, is increasing, two thirds of MOOC students are from the United States and Europe.

Access to MOOCs in LDCs and remote areas of other developing countries, particularly, is constrained by often limited and unreliable Internet access. This underscores the importance of reducing the digital divide. Other important constraints to inclusivity of MOOC learning are the skills and knowledge required, and financial costs, as providers become more focused on monetization. At least 60 per cent of MOOC students have already completed at least a bachelor's degree, while more than half are in full-time employment or self-employment (Music and Vincent-Lancrin, 2016). Moreover, content is mostly in English, further limiting access; and it is not necessarily relevant or suitable to local contexts and educational needs and priorities in developing countries.

As with other kinds of training and lifelong learning activities, another challenge is recognition of qualifications, particularly because employers often value online education less than traditional education (Deming et al., 2015). While this can be improved by appropriate accreditation systems, obtaining credentials from MOOCs may imply a financial cost, limiting the advantage of open online learning. One approach is a national skills and qualification framework, such as India's National Skills Qualifications Framework, which allows certification of competency at any level through formal, non-formal or informal learning. More than 150 countries are reforming qualification systems to this end (UNESCO, 2015).

[61] Examples of MOOCs include Coursera, founded by Stanford University, which aggregates courses from a variety of institutions; the more technologically focused Udacity, which provides nanodegrees for speedy capacitation in new competencies; and edX, developed by the Massachusetts Institute of Technology and Harvard University. Khan Academy is particularly useful for teaching at early ages.

### *b. Universal basic income*

The risk of future job losses, with many workers unable to adapt to the changing demands of the labour market, is among the main concerns raised by the prospect of future large-scale deployment of frontier technologies. Such risks pose an important threat to, the principle of inclusiveness fundamental to a development agenda that aspires to leave no one behind. The concept of a minimum income available to every member of a society, now generally referred to as universal basic income, is being increasingly debated as a possible response to such fears.

Several developed and developing and countries have experimented with UBI programmes locally, including the United States (the Developed country cases include the andostm of aal impact ofeds ofisms approaches ogical and developmental context for STI policAlaska Permanent Fund, since 1976), Canada (Manitoba Mincome, 1974–1979), India (the Madhya Pradesh Unconditional Cash Transfer, 2011-2013), Brazil (in Quantinga Velho since 2008, and in Maricá since 2015) and Namibia (the Otjivero–Omitara Basic Income Grant Pilot Project, 2008–2009). Kenya's GiveDirectly, a privately funded scheme operational since 2011, is the most significant UBI scheme in developing countries, in terms both of scale (covering 300 villages) and of planned duration (up to 12 years). Other UBI schemes were launched or planned in 2017 at the local level in the United States, Netherlands and Italy, while Finland has initiated a small-scale controlled experiment on the use of a partial basic income model at the national level (box 3.5).

While controversial, UBI has supporters on both sides of the ideological divide. Some proponents emphasize its role in promoting social justice and redistribution and to support consumption and demand; others stress its potential to limit welfare programmes, to reduce the associated bureaucratic burden and fraud, and to reduce public sector influence on markets operations and individual choices. By providing a minimum element of economic and social inclusiveness, UBI could also help to sustain aggregate demand and reduce the risk of social and political unrest; and it may offer an economically efficient means of distributing the rents generated by natural-resource endowments in resource-rich developing countries.

An additional benefit of a UBI, particularly pertinent in the present context, is its potential to promote innovation and entrepreneurship by allowing more time for creativity and providing the basic financial security needed to limit the risks involved. As Facebook founder Mark Zuckerberg (2017) has observed:

"An entrepreneurial culture thrives when it's easy to try lots of new ideas … The greatest successes come from having the freedom to fail … Right now, our society is way over-indexed on rewarding success and we don't do nearly enough to make it easy for everyone to take lots of shots… I know a lot of entrepreneurs, and I don't know a single person who gave up on starting a business because they might not make enough money. But I know lots of people who haven't pursued dreams because they didn't have a cushion to fall back on if they failed … We should explore ideas like universal basic income to give everyone a cushion to try new things" (Zuckerberg, 2017).

**Box 3.5 Finland's partial basic income experiment, 2017–2018**

Basic income is a key project of the current Government of Finland. It put out a tender for proposals to conduct a controlled experiment on the application of UBI in late 2015, and contracted the Research Department of the Finnish Social Insurance Institution (Kela) to carry it out in 2017–2018.

Following preliminary work by Kela on project design, it was decided to base the experiment on a partial basic income model, whereby the basic income did not replace old-age pensions and only partly replaced unemployment benefits. The target group was people aged 25–58 years receiving a basic daily allowance or labour market support. Within this target group, 2,000 people were assigned to receive a basic income of €560 per month, deducted from their benefits, while the remainder of the group (some 175,000 people) were treated as a control group. Participation was mandatory; and the payment was set at such a level as not to reduce the net income of participants. This reflects the relatively narrow objective of the experiment, to assess the effects of basic income on incentives for labour market participation, and limits the conclusions that can be drawn about other effects.

*Source:* Kangas et al. (2017).

A general concern that has been raised regarding UBI is its potential to reduce labour supply, by weakening incentives for employment.[62] In the present context, however, this is not necessarily a disadvantage: provided any reduction in labour supply was not excessive, its effect would be to counter the medium-term (and possibly long-term) reduction in labour demand anticipated as a result of rapid technological change, moderating the net impact on labour markets. Provided the UBI was set at a level below the living standard to which most people aspired, reduced labour supply could be expected to take the form of a reduction in each individual's working hours, allowing the reduced employment opportunities and labour income to be distributed more widely.

While the empirical evidence is limited and based only on small-scale local programmes, direct cash transfers have been found to be an effective way of addressing extreme poverty at a low administrative cost (through digital technologies), without distorting market signals. Results from developing countries indicate positive effects on access to health and education, nutrition, microentrepreneurial activity and women's empowerment. Favourable effects on health and education outcomes and poverty have also been observed in developed countries, while effects on labour-force participation have been limited.

By simultaneously promoting innovation, strengthening social protection and increasing financial security, UBI could, in principle, play a major role in reconciling rapid and disruptive technological change with sustainable and inclusive development; and cost–benefit analyses of current experiments should provide valuable evidence on the usefulness of a UBI in this context.

However, the considerable fiscal cost of a UBI represents a particular obstacle in the current global macroeconomic context. While direct costs would be partly offset by a reduction in the cost (including administrative costs) of other forms of social protection such as pensions and unemployment benefits, where these currently exist, the net cost would be considerable. Consequently, financing a UBI through a flat-rate income tax would likely require a very high marginal tax rate, seriously affecting incentives for labour market participation (Kangas et al., 2017). This suggests a need to investigate other sources of financing, such as the "robot tax" proposed by Microsoft founder Bill Gates as a means of managing the pace of innovation and creating new employment in social provision to limit the impact of, and resistance to, technological progress (Delaney, 2017).

Analyses of current experiments with UBI and cash transfers should provide at least a preliminary indication as to whether its benefits would generally justify its net fiscal costs. If this is the case, the disincentive to unilateral implementation arising from the effects of the necessary tax increases on competitiveness might suggest a case for an internationally coordinated system of UBI, at differentiated levels between countries according to living costs. However, the scale of the fiscal costs and the severity of financial constraints in many developing countries (particularly LDCs) would suggest a need for cross-subsidization between higher- and lower-income countries, and/or for innovative financing at the global level (in the original sense of mechanisms with the potential to provide genuinely additional resources for development on a large scale and without undue restriction on their use (United Nations Department of Economic and Social Affairs, 2012).

## D. CONCLUSIONS

As discussed in chapter I, frontier technologies have immense potential to contribute to sustainable and inclusive development, and could make a major contribution to the achievement of the Sustainable Development Goals. However, harnessing this potential will require the establishment of effective innovation systems in developing countries, through the development of capabilities and connections among the key actors, and strengthening regulatory and policy frameworks, institutions and governance, entrepreneurial ecosystems, access to finance, human capital and technical and R&D infrastructure. It also requires a reorientation of STI policies to address the three pillars of sustainable development, and their integration into national development strategies, to ensure policy coherence and optimize the contribution of technological change to societal goals.

Also essential is to address the potential social costs of the disruptive effects of rapid technological change, particularly on labour markets, over the short and medium term. This highlights the importance of lifelong learning, for skills updating as well as skills upgrading, which will require active policy support. Strengthened social protection

[62] Alternative approaches intended to limit potential disincentives to work include a negative income tax (such as the Earned Income Tax Credit in the United States) and a shift of the tax burden from labour income towards Pigouvian taxes on negative externalities (Brynjolfsson and McAfee, 2016).

is also important, to offset negative impacts on employment and protect those unable to adapt to rapidly changing skills requirements. Growing concern about the potential social impact of rapid technological change has led to a renewal of interest in the idea of a universal basic income, including several experimental applications, mostly at the local level. While the globalization of markets for goods, services and financial and human capital represents an important constraint, given its high fiscal cost, consideration could be given to strengthened international coordination in this area – possibly including a global UBI – if this is merited by the results of such experiments.

Beyond these foundations of STI policy for inclusive and sustainable development, several new approaches are emerging – notably in technology, industrial policy and finance – that could further strengthen the contribution of technological change to the 2030 Agenda for Sustainable Development and the achievement of the Sustainable Development Goals. These are explored in chapter IV.

**Box 3.6 Key messages and conclusions**

(a) To benefit from both existing and frontier technologies, developing countries should learn, adapt and disseminate knowledge and technologies. This requires an environment that nurtures learning and innovation, and the dedication of resources, time and effort to build and manage effective innovation systems.

(b) Developing countries need public innovation support that is long-term, and effective institutional frameworks. Three key areas require policy attention:

- (i) First, improving the capabilities of key actors, including firms and entrepreneurs, systems of research and education, government policymakers, and strengthening engagement with civil society and citizens;
- (ii) Second, forming and strengthening linkages between and among key actors to promote knowledge flows and collaboration, domestically and internationally;
- (iii) Third, improving at least five building blocks of innovation systems to enable innovation and technological upgrading: the regulatory framework, the institutional setting and governance, the entrepreneurial system and access to finance, human capital, and the technical and R&D infrastructure (including ICTs).

(c) Building the foundations for effective STI policy requires at least five things: assuming a systemic approach to STI policy, adopting a broad definition of innovation, improving STI priority setting, mainstreaming and better integrating STI policies, and improving policymaking and implementation capacity.

(d) STI policies must be aligned with national development plans and provide adequate vertical, horizontal and temporal policy coherence. Coherence is needed between STI policy and industrial policies and those on STI, FDI, trade, education and competition, along with macroeconomic policies.

(e) Promoting access to affordable financing for innovation is a fundamental challenge. Financing instruments should go well beyond research. Early stage financing should build in high expected failure rates as innovation is highly uncertain. Financing should aim to create “additionality” by “crowding in” investment. Financing should be accompanied by measures to strengthen the entrepreneurial base. Financing programmes can be undermined by a lack of fiscal space – using royalties provides an interesting example for commodity-dependent countries.

(f) To meet the Sustainable Development Goals, IP regimes should recognize the principle of policy flexibility, and special and differential treatment for developing countries, rather than focusing exclusively on increasing IP protection. Intellectual property systems should be appropriate for a country’s level of technological and industrial development. Countries with weak technological capabilities, such as LDCs, need adequate policy space to build their technological capabilities.

(g) Policymakers need to be cognizant that STI policy has broad strategic focus beyond purely economic concerns, but also contribute towards addressing inclusiveness and sustainability.

(h) To respond to rapid technological change, countries will need to match skills to future needs, reform education and training systems (including technical and vocational education and training) and promote lifelong learning.

(i) The implications of frontier technologies on society are yet uncertain; providing a safety net for those who may be adversely affected can encourage innovation and creativity by lowering its risks. In this regard, countries could learn from ongoing experimentation with universal basic income programmes, and the potential of applying for future social protection initiatives.

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# CHAPTER IV

## FRONTIER TECHNOLOGIES, EMERGING APPROACHES AND OPPORTUNITIES

Changes in the environment for STI policy are not limited to the technological landscape and development goals discussed in chapters I to III. There have also been a number of important developments in conceptual and policy approaches to technology and innovation, some of these reflecting the nature of frontier technologies, particularly the opportunities for networking and collaboration that digital technologies and platforms afford. A key part of building on the foundations of STI policy outlined in chapter III is to apply these new concepts effectively and to make optimal use of new opportunities and emerging policy approaches.

This chapter discusses these new concepts, opportunities and policy approaches from the perspective of STI policy for inclusive and sustainable development. It begins, in section A, with a discussion of the potential and limitations of technological leapfrogging as a means to development. Section B discusses new forms of innovation relevant to the goal of inclusivity. Sections C and D outline two specific policy approaches – smart specialization strategies and platforms for economic discovery. Section E discusses innovative approaches to STI financing, section F the use of accelerators, incubators and technology parks to promote innovation, and section G global collaboration in scientific research.

## A. LEAPFROGGING: LOOK BEFORE YOU LEAP?

Discussions of the developmental dimension of frontier technologies, particularly digital technologies, often highlight the possibility of "leapfrogging". The traditional notion of "catch-up" refers to the narrowing of gaps in income and technological capabilities between a late-developing country and a front-runner country (Odagiri et. al., 2010). Historically, this has entailed a sequential process of learning by latecomers in skills, process technology, design technology and new product development (Lee, 2005).

The need to learn product design and acquire the capability to produce new products has been a major barrier, as frontrunner firms are generally unwilling to grant licenses to catching-up firms. However, the nature of recent technological advances, notably in ICT and energy, means that catch-up no longer necessarily requires following the historical paths of frontrunners, but may rather be achieved by technological "leapfrogging" – that is, bypassing intermediate stages of technology through which countries have historically passed during the development process (Lee, 2016; Steinmueller, 2001).

A key distinction is that between leapfrogging through the development of new technologies and leapfrogging through the adoption of technologies that have been developed elsewhere. A few countries, notably the Republic of Korea and Taiwan Province of China, have achieved rapid economic growth by successfully leapfrogging in the development of a limited number of short-cycle technology sectors such as semiconductors and other electronic goods, skipping certain stages through which leading foreign firms passed in technological development. Typically, such latecomers have begun with assembly of final goods using imported parts, moving on to the development of low-tech and then progressively higher-tech components, before learning to modify the design of existing products, and ultimately to develop new products (Lee and Lim, 2001).

For many developing countries, however, leapfrogging in the industrial sector, particularly through the development of new technologies, is beset with challenges. Catch-up, whether in the historical sense, or through leapfrogging, requires the learning of modern technologies and accumulation of indigenous technological capabilities in innovation and technological know-how for production, as well as investment in physical assets (Odagiri et. al., 2010); and the development of upstream industries requires a manufacturing base with innovation capabilities, which is often lacking, especially in LDCs. Moreover, technological learning and innovation in the Republic of Korea and Taiwan Province of China benefited greatly from reverse engineering, which allowed the build-up of capabilities in the creation of new products; and the advent of more stringent IPR protection represents an additional barrier to this course.

In most developing countries, even the ability to leapfrog through adoption of existing technologies varies between technologies and sectors. The recent increase in attention to technological leapfrogging has been motivated in large part by the experience of the ICT sector. Rapid technological advances and associated cost reductions in ICT in recent decades (chapter I) have enabled some developing countries, notably in Africa, to skip the development of analogue landline infrastructure by moving directly to digital mobile telecommunications. As well as contributing

**Box 4.1 FinTech**

FinTech is a generic term for organizational innovations using digital technologies that offer new business models for providing financial services. It encompasses several types of firms, including both start-ups offering digitally based financial services, and established telecoms firms and online retailers that use their ICT capabilities and customer bases to provide digital financial services, such as mobile telephone-based money, payments and banking services. Examples include M-Pesa, created in 2007 by Safaricom, a subsidiary of Vodacom in Kenya, and mobile money and payments systems such as AliBaba's Alipay in China and Apple's Apple Pay in the United States. Some operate using blockchain technology, which offers an alternative approach to storing and transferring data.

These firms have disrupted traditional financial institutions, such as commercial banks, which have followed them in establishing online financial services through electronic platforms. However, the latter remain relatively risk-averse, and are (appropriately) subject to stricter prudential financial regulation and oversight. FinTech has contributed to increasing financial inclusiveness by making basic financial services more widely available to populations previously excluded from the services provided by traditional financial institutions.

*Source:* UNCTAD secretariat

to increasing productivity and the creation of new markets, this has paved the way for innovative FinTech services such as the M-Pesa mobile banking system in Kenya, with important implications for financial inclusion (box 4.1). Despite such spillover effects and significant potential welfare benefits, however, leapfrogging through the adoption of consumer ICT technologies is unlikely to be sufficient to bring LDC economies significantly closer to the technological frontier in the absence of widespread technological capabilities in other sectors.[63]

Advances in ICTs have been hailed as opening up opportunities to bypass the manufacturing stage of development to leapfrog into the services economy – and some developing countries have moved in this direction, participating in global value chains through global outsourcing in ICT services. As yet, however, relatively few countries have succeeded in developing substantial activities in this area, partly due to stringent requirements in terms of infrastructure, quality and costs. Moreover, benefits to the poorer segments of society are not automatic, and largely limited to second-order effects such as indirect job creation. Even in the successful cases of India and the Philippines, most direct and indirect job creation has occurred in a few major urban agglomerations (UNCTAD, 2010).

Successful as it has been in many respects, Africa's mobile revolution also demonstrates the limitations of leapfrogging. Despite their potential developmental role, the economic impact of ICTs in sub-Saharan Africa in recent years appears smaller than in other regions (WEF, 2016). This partly reflects the limitations of innovation policy in Africa to coevolve with the development of ICT, which has resulted in opportunities to build on the mobile revolution to foster innovation and development not being fully exploited (Juma and Lee, 2005). As well as adoption of ICTs, catching up requires ensuring an adequate and reliable energy supply and availability of the skills needed to enhance productivity and stimulate innovation. Moreover, sustaining progress requires a constant process of innovation and investment in the latest technologies to keep pace with continuing rapid technological change in the sector (WEF, 2016). Investment in extensive broadband installation, building absorption capabilities and skills development are also needed, to ensure that digitization does not exacerbate the digital divide within societies (UNCTAD, 2017).

The energy sector is often seen as a parallel to ICTs, offering an opportunity to leapfrog to decentralized renewable energy systems through the adoption of new technologies, bypassing traditional reliance on fossil fuels; and some developing countries have made substantial progress in this direction. As in the ICT sector, international prices in renewables have fallen dramatically in recent years as investments in their development have increased: the cost of wind turbines has fallen by nearly a third, and that of solar photovoltaic (PV) modules by 80 per cent since 2009 (International Renewable Energy Agency, 2016), making both increasingly competitive with fossil fuel generation. This suggests that leapfrogging in energy systems may be a viable path to economic development, as well as promoting a "green

[63] See *The Economist* (2017).

economy"[64] and contributing to climate change mitigation.

Innovation policies can certainly help to promote and facilitate the development, adaptation, deployment and use of renewable energy technologies to support sustainable development. However, if the transition of developing countries from fossil fuels to renewable energy is to be a catalyst for industrial development and structural change, it needs to be backed by finance and investment, technology transfer and other supportive measures to ensure adequate energy supply at reasonable costs (UNCTAD, 2011a). In LDCs particularly, such a transition itself requires overcoming important technological, economic, financial and governance obstacles (UNCTAD, 2017).

Again, the distinction between leapfrogging through the adoption of existing technologies and leapfrogging through the development of new technologies is critical. In both ICT and renewable energy, the transformative potential of leapfrogging is limited by the obstacles of backward linkages to the production of (and still more to innovation in) related equipment. ICT *services* and renewable electricity *generation* require only the adoption of technologies and entail little risk; but *manufacturing* of ICT and renewable energy equipment is characterized by high concentration of global production and exports, significant economies of scale and high barriers to market entry. Leapfrogging in the design and manufacture of technologies entails innovation in design and product development, which requires much more advanced capabilities than leapfrogging through technology adoption. In most developing countries, technological capabilities thus represent an important constraint, compounded by the complexity and irregularity of technological leapfrogging in the development of upstream industries.

Hence, only a limited number of developing countries have yet made their mark as developers of renewable energy technologies – most notably Brazil, now the second largest producer of liquid biofuels for transport after the United States (WEC, 2016), and China, which produces the majority of the world's PV and solar thermal heating technologies (International Renewable Energy Agency, 2016). Ultimately, long-term technological innovation depends on industrial development and a manufacturing base, and thus on the hard and soft infrastructure for such development (Juma, 2017).

Nonetheless, leapfrogging through technology adoption in sectors such as ICT and renewable energy can provide a cost-effective means of accelerating sustainable development, and may open further leapfrogging opportunities in other areas. International initiatives such as the United Nations' multi-stakeholder forum on STI and the Technology Bank for LDCs offer useful knowledge-sharing platforms enabling developing countries to make informed policy choices on frontier technologies in such areas.

In leapfrogging as in other contexts, technological learning and innovation need to be appropriate to each country's level of technological development, its economic structure and the capabilities of its public institutions and private sector (UNCTAD, 2007). The potential to harness and sustain a development trajectory based on leapfrogging depends on the state of infrastructure, institutional capacity and other sources of externalities, which are lacking in many developing countries, particularly in the early stages of technological development (Fong, 2008). Also important are the selection of technological standards appropriate to local circumstances (Lee, 2005) and the development of markets for complementary technologies, given the systemic nature of ICT and energy and their linkages with other sectors (Steinmueller, 2001).

## B. EXTENDING BENEFICIARIES: ALTERNATIVE MODES OF INNOVATION

As noted in chapter I, business as usual will not suffice to deliver fully on the 2030 Agenda for Sustainable Development. New approaches are needed, within which the notions of directionality and participation are essential. This means that innovation should be approached as a phenomenon that takes place within networks of actors in which civil society plays a central role. Harnessing innovation for sustainable and inclusive development requires changes in the direction of key economic and social processes (for example with regards to sustainable patterns of production and consumption) which cannot take place without the strong involvement of civil society. That is why growing attention is being given to several

[64] The "green economy" can be defined as economic development that is cognizant of environmental and equity considerations and promotes the Earth's environment while contributing to poverty alleviation (UNCTAD, 2011a).

new approaches to innovation. Such approaches are variously termed pro-poor, inclusive, below-the-radar, frugal, bottom-of-the-pyramid, grass-roots and social innovation, largely reflecting differences in emphasis. This section considers some of the broad themes underlying these approaches, and highlights policy options to promote them.

**Pro-poor and inclusive innovation** approaches are concerned primarily with extending the benefits of innovation to previously excluded groups, either as consumers of new products and services or as participants in the innovation process (box 4.2). The main focus is on developing low-cost products and services and new commercialization and distribution strategies to serve untapped markets, such as low-cost medical products and mobile telemedicine clinics in remote rural areas; and innovations that strengthen the entrepreneurial skills of people living in poverty, to help raise their incomes. The development of a mobile application to strengthen the entrepreneurial capacity of rural women in India, for example, helped to increase their efficiency and reduce their travel costs.

The concept of **frugal innovation** focuses on innovation by marginalized groups themselves, particularly informal forms of innovation in contexts of scarcity. Such innovation often entails building on simple ideas and local knowledge, as in the case of solar "bulbs" – reused plastic bottles filled with bleach-treated water, providing light at minimal cost to poor households without access to electricity in the Philippines and elsewhere (Radjou, Prabhu and Ahuja, 2012). Another example of frugal innovation is MittiCool, a low-cost refrigerator made of sustainable materials, which works without electricity, using water evaporation as a cooler. It is easy to produce, at a cost of $30–$50, and can keep food fresh for two to three days. MittiCool has been supported by the National Innovation Foundation of India (2009).

Several governments and development institutions have used different policy tools to support pro-poor and inclusive innovation, including seed-funding schemes for small producers, new financial services and infrastructure for the development of local markets, and innovation in new products. There have also been successful examples of inclusive public procurement programmes to stimulate innovative entrepreneurship among groups of population at particular risk of exclusion or with limited involvement in innovative activity, including women entrepreneurs, for example, in the Dominican Republic.[65] The effectiveness of inclusive innovation programmes can be enhanced by integrated design approaches that include both the beneficiaries and the agents involved in implementation (UNCTAD, 2014a).

**Grass-roots innovation** approaches seek to practise innovation, in both technology and service provision, in ways that include local communities in the knowledge, processes and outcomes involved (box 4.2). This is done primarily through the involvement of grass-roots actors, such as civil society, social movements and networks of academics, activists and practitioners experimenting with alternative forms of knowledge-creation and innovation processes (Fressoli et al.,

[65] See presentation by the Dominican Republic at the twentieth session of the United Nations Commission on Science and Technology for Development on 10 May 2017 in Geneva, available at: http://unctad.org/meetings/en/Presentation/enc162017p12_YokastaGuzman_es.pdf (accessed 25 March 2018).

**Box 4.2 Grass-roots innovation: Examples**

The maker movement, a popular contemporary innovation movement, has become a global driver of informal experimentation with technologies such as software, microelectronics, robotics and digital fabrication. Its main aims are to experiment with artefacts and modify them for novel purposes, and to create unrestricted access to technology. It links traditional knowledge about carpentry, metallurgy and mechanics with new technologies such as software programming and basic electronics. The Internet has enabled the spread of maker culture by connecting amateurs, practitioners and experts worldwide, and fostering collaboration and learning (Anderson, 2012).

The One Million Cisterns project aims to provide water cisterns in a large semi-arid region in North-eastern Brazil. The project was initiated by the Semi-Arid Association, a network of more than 700 institutions, NGOs, social movements and farmers' groups. The technology is developed by users, fostering relationship-building in the community through the process of learning to construct, use and modify the technology. Almost 590,000 water cisterns have been built since the programme was included in national development policies funded by the Ministry of Social Development in 2003.

*Source:* Smith et al., 2016.

2014). Grass-roots innovation initiatives operate in civil society arenas, driven by social and environmental needs, rather than competitiveness or profit, based on mutual exchange, voluntary inputs from actors and local knowledge, often supported by grant funding.

Development agencies and mainstream science and technology institutions have historically shown significant interest in alternative models of technological change and social development originating in grass-roots innovation movements (Ely et al., 2013; Fressoli et al., 2014). Policies to support grass-roots innovation include funding programmes for the acquisition of tools and for experimentation with new technologies and capabilities. Policies may also be aimed at building bridges between heterogeneous informal grass-roots innovation initiatives and existing research and development capabilities; and building infrastructure such as repositories and innovation platforms to foster the distribution, replication and improvement of innovations and ideas from the grass roots. Initiatives can also support international networks to foster local grass-roots movements and increase their visibility and legitimacy.

However, grass-roots innovation often thrives due to its independence from bureaucratic procedures and formal institutions. In supporting such innovation, it is therefore important for mainstream institutions to avoid imposing their own objectives.

**Social innovation** focuses on the creation and diffusion of novel social practices and institutions, as opposed to technologies (box 4.3). It generally refers to innovations in social relationships, practices and structures that are primarily aimed at addressing social needs and improving human well-being (van der Have and Rubalcaba, 2016). Most social innovations are bottom-up, initiated by the entrepreneurial activities of civil society actors such as cooperatives, associations and foundations. The main driver is an ecosystem of networks and groups of individuals bound together by a shared vision of solidarity with beneficiaries (Millard et al., 2016). An example is the development by the global fair trade movement of new production models linking social movements, producers and mainstream firms and their associated norms in novel ways.

While the community-driven nature of social innovation limits the potential for scaling up and the role of policies, appropriate interventions may include grants and managerial and technical support to community initiatives, and financing for research.

In order to support the implementation of the Sustainable Development Goals, innovative approaches such as those discussed in this section must be considered in combination with innovation driven by the private sector in a more traditional sense. This is particularly relevant for Goals 8 and 9. Evidence about the potential results of such a synergic relationship between both modes of innovation is discussed in Fu et al. (2014) and Fu (2018). The following sections explore some policy approaches that may prove useful in this regard.

**Box 4.3 Social innovation: Examples**

New approaches are reshaping traditional ways of accessing capital, creating alternative sources of finance and contributing to community and business initiatives unable to secure funding from traditional credit markets. Online crowdfunding platforms (such as Crowdfunder, Indiegogo and Kickstarter), though currently concentrated in the developed world, could become an important tool for fundraising in developing countries. In the Islamic Republic of Iran, for example, websites such as https://hamsaa.ir/ and http://ichallenge.ir/ (both accessed 25 March 2018) are platforms for crowdsourcing solutions to both public and private needs. Peer-to-peer lending platforms such as Kiva allow people to lend money online to low-income entrepreneurs and students in developing countries.

Several countries have implemented policies to support social innovations, to identify and foster innovations that appear promising, especially in traditional areas of welfare and public policy, and to transfer, replicate and scale-up successful models. In the United States, for example, the Social Innovation Fund provides grants and managerial and technical support to community initiatives. The European Commission aims to encourage market uptake of social innovations through funding mechanisms (via its Employment and Social Innovation Programme), networking support, an annual social innovation competition and financing of research on social innovation and how it can best be supported.

However, such interventions face a number of challenges. In particular, social innovation initiatives are community-driven, and reflect local sociopolitical and cultural contexts and the motivations of those involved, which are difficult to affect by policy. Consequently, such initiatives are often difficult to replicate, scale up and diffuse.

*Sources:* Millard et al., 2016; Pel et al., 2015.

## C. SMART SPECIALIZATION: INNOVATION AS A STRATEGY FOR COMPETITIVE ADVANTAGE

This section explores the potential usefulness for developing countries of smart specialization strategies (S3). While the S3 approach, based on a seminal policy paper (Foray et al., 2009), is closely related to traditional vertical industrial policies, it differs in making the experimental nature of such policies explicit, systematizing and responding to the information generated by positive and negative results, which is itself viewed as an important product of the strategy. S3 strategies are considered here because of their primary focus on innovation and technology for driving industrial policy measures, whereas other approaches to industrial policy (for example, those associated closely with Justin Lin or Hidalgo and Haussmann) place less emphasis on these policy aspects.[66]

The S3 approach is itself a large-scale experiment in innovation policy, conducted within the framework of the European regional cohesion programme since 2011, and integrated into the European Union's reformed cohesion policy for 2014–2020. European Union member States and regions[67] have developed more than 120 S3s establishing priorities for research and innovation investments for 2014–2020, supported by more than € 65 billion in funding from the European Regional Development Fund and national co-financing, with advice on design and implementation available on an online S3 platform[68] (European Commission, 2017). Although initiated in advanced Western European economies, the S3 approach has also attracted much attention elsewhere, notably in Argentina, Australia, Brazil, the Russian Federation, Serbia, Tunisia and Ukraine.

### 1. The S3 approach

An S3 comprises a small portfolio of transformative activities, managed at the regional level and modified over time, aimed at transforming a region's economic structure. Transformative activities are collections of innovation capacities and actions oriented towards a particular structural change, which are developed from one or more existing structures, supported by extraregional capacities. Rather than encompassing an entire sector, they may be limited to a subgroup of companies, suppliers and research partners that are prepared to embark on collective action to transform their capacities.

Transformative activities seek to focus R&D projects, partnerships and the supply of specific new public goods on exploring a particular new area of opportunity and facilitating collective actions among innovation actors. The aim of S3 is to address the particular capability and infrastructure needs of transformative activities, tailoring policies to the specificity of each. The basic mode of operation is not necessarily through collaborative projects, but rather through the development of coordination and links between entities and projects to facilitate spillovers, economies of variety and scale, and the supply of specific public goods and infrastructure to the technology or sector in question.

Structural changes follow different logics – of modernization, transition, diversification and radical foundation (Foray, 2015). Innovation is thus not focused only on high tech and formal R&D, but widely distributed across the whole spectrum of sectors and invention processes. A transformative activity aimed at the foundation of a new industry might be oriented towards high tech start-ups and the formation and attraction of specialized human capital. In many regions, however, the primary consideration is not invention at the technological frontier, but rather generating the innovation complementarities in existing sectors that ultimately represent the key to economy-wide regional growth. Thus, depending on its objective, the components of a transformative activity may include training programmes, the formation of new managerial and engineering skills, quality control and certification processes, as well as technology adoption.

### 2. S3 as a vertical policy approach

S3 is a departure from the neutral or horizontal policies, aimed at improving general conditions and fixing generic problems, that have dominated the

66 See for example, UNCTAD (2014c, 2006), Lin (2012), Lin and Treichel (2012), Hidalgo and Haussmann (2009) and Cimoli et al. (2009).

67 While its primary focus is on regions, the S3 approach is flexible in terms of the administrative entities supported. Smaller countries such as Slovenia and Estonia have adopted national S3s, while city, subregional and interregional S3s are also considered. The primary consideration is consistency between the administrative level of the S3 and the type of structural changes sought.

68 Available at http://s3platform.jrc.ec.europa.eu (accessed 25 March 2018).

European political landscape in recent decades.[69] It also goes beyond the regional innovation system approach, focused on building regional institutional frameworks for innovation, by abandoning the principle of neutrality between sectors in favour of a much higher degree of intentionality, centralization, prioritization and commitment to new specialization. This implies a different policy design.

The idea that regions should seek to discover and choose, in detail, priority areas for R&D and innovation long predates the era of smart specialization (Enos, 1995). It reflects both defensive and proactive motivations: that priorities will be established by global players if they are not specified by regions themselves; and that the knowledge and experience acquired from prioritization of R&D and innovation is beneficial in the subsequent stages of product/process/market design, production and distribution. Thus, the identification of priorities and transformative activities is itself a valuable process of learning about region-specific capacities and opportunities, in collaboration with key innovation actors (firms and universities), which lies at the heart of S3.

It should be emphasized, however, that the logic of smart specialization does not reduce the importance of the fundamentals of STI policy discussed in chapter III. Rather, it provides an additional option, complementary to horizontal policies, for regions that have the capacity to identify priorities and to develop transformative activities effectively.

## 3. Establishing priorities

Any non-neutral policy, by definition, must identify strategic priorities. This raises the issue of how to minimize policy capture and avoid monopolization of resources by a small number of actors. Two principles emerge as important in this regard.

First, the selection of priorities should be carried out, not at the level of the sector or of the individual enterprise, but at the intermediate level of the transformative activity – not the footwear industry itself or an individual footwear producer, for example, but the development of flexible footwear manufacturing technologies. This level best reveals the domains in which a region should position itself, while allowing domains to be defined narrowly enough to facilitate connections, synergies and spillovers, and thus provide benefits of scale and scope.

Second, the key to successful identification of transformative activities is a robust and transparent decentralized process of interaction between the public and private sectors, supported by evidence on the regional economy and knowledge of the region's entrepreneurial activities and capacities. This can contribute to the identification of the desired structural changes and the selection of a small number of combinations of existing capacities and new opportunities for transforming regional structures.

## 4. Developing transformative activities

Once a transformative activity has been identified as a priority, a wide spectrum of policy instruments is deployed, to support the exploration of opportunities, provide the public goods required (training, basic research, etc.), and establish mechanisms to assist in the formation of networks and partnerships within this narrowly defined area. Three design principles are important.

First, the interaction between human capital and R&D needs to be taken into account in policy sequencing – otherwise, inelastic short-term supply of specialized human capital may result in higher R&D expenditure inflating the wages of R&D personnel rather than increasing innovation (Romer, ). Consequently, the formation of specialized human capital and capabilities needs to precede, or occur in parallel with, policies that increase demand for R&D. In the Basque Country of Spain, for example, the transformative activity addressing modernization of the engineering and mechanical industry includes new university training programmes in parallel with conventional R&D support (Navarro et al., 2011).

Second, transformative activities need to encompass actions to facilitate the *adoption* of new technologies and strengthen absorptive capacity, as well as their *development*. Otherwise, the activity will remain limited to start-ups and fail to realize its transformative nature, and may further widen the gap between dynamic and non-dynamic sectors of the economy.

Third, it is important to avoid an excessive number of poorly coordinated policy instruments, which is likely to prove ineffectual and costly. The Tinbergen assignment theorem provides first-order guidance on the number

[69] Vertical (also called "selective" or "targeted") industrial policies have been, and remain, widely used across most developing and developed countries. They played an important role, for example, in the industrialization of the East Asian "tiger" economies (UNCTAD, 2014c; Wade, 2003).

of instruments needed to achieve a target. In general, the number of instruments should correspond with the number of externalities or market failures (Jaffe et al., 2004). In the agri-food sector, for example, instruments are needed to address knowledge externalities and capital market imperfections that impede research and start-ups; adoption, network and training externalities in the traditional sector; and coordination failures at the interface between the high-tech and traditional sectors. This suggests around five instruments. The selection of the appropriate instruments ultimately falls to the Government, which is thus “doomed to choose” (Hausmann and Rodrik, 2006).

## 5. S3 as experimental policy

S3 policies are, by nature, experimental: by definition, some transformative activities will be successful, while others will not be. This is inherent in the nature of vertical industrial policies more generally, which are not about “picking winners” but “picking possibles” (UNCTAD, 2014d) – identifying support activities with the potential to succeed and to contribute positively to economic transformation. This essentially experimental nature means that vertical policies give rise to much greater risks than horizontal policies, such as economy-wide R&D tax credits, whose likely effects can be anticipated on the basis of past experiments and evaluations. This has important implications for policy design.

First, **entrepreneurial discovery** (Kirzner, 1997) plays a central role. This entails learning about the development possibilities and structural effects offered by each transformative activity as it unfolds, through the successes, failures and unanticipated effects of its elements. It operates at two levels: the success or failure of individual projects, and overall progress towards the targeted structural change. The resulting learning about opportunities, constraints and challenges should inform the development of transformative activities. Integrating entrepreneurial discovery in industrial policy design, as proposed by Haussmann and Rodrik (2002), helps to reconcile the logic of strategic choice and prioritization with that of decentralized and entrepreneurial information and initiatives, and to avoid centralized planning.

Second, **flexibility** is essential. Once identified, transformative activities and their components are not unalterable, but should be adapted – or if necessary discontinued – in the light of entrepreneurial discovery, while newly identified priorities may also be integrated. Monitoring is critical, to gauge performance, progress and the direction and magnitude of changes, and to identify potential failures, structural deficiencies and issues warranting further investigation. Indicators should be identified and monitored to provide an up-to-the-minute barometer of the activity to provide immediate feedback as a basis for policy adjustment (Feldman et al., 2014).

A third key principle is the **maximization of informational spillovers** created by the discovery process. The social value of the entrepreneurial discovery process lies in informing the whole system about new opportunities, successes and failures in R&D and innovation to generate desirable structural changes. This is what distinguishes entrepreneurial discoveries supported by public policy from those made by individual firms. This means requiring companies supported in joining the entrepreneurial discovery process to conform to appropriate information rules, and ensuring that rewards for entrepreneurial discovery are structured to maximize spillovers to other participants and potential entrants in the transformative activity (Rodrik, 2004).

Entrepreneurial discovery thus means providing firms with incentives to explore new opportunities within the framework of a transformative activity, without dictating the content or direction of their projects; continuously evaluating progress, blockages and surprises; ensuring the diffusion of information to the industrial base concerned; and responding appropriately with decisions on the continuation or interruption of projects. These principles are being put in place in some regions, notably the Basque Country (Morgan, 2016).

The S3 approach is thus neither purely bottom-up (in that priorities are ultimately chosen by the government) nor purely top-down (by virtue of design principles such as the entrepreneurial discovery process and public–private interactions). Rather, it is an intermediate process aimed at enhancing entrepreneurial coordination, within a framework structured by the government.

## 6. Experience with S3 to date

It is too early to evaluate the impact of S3 on innovation, productivity and growth, and systematic evaluations cannot be expected for some years. However, numerous case studies indicate some success in enabling regions both to build capacities and to transform their economic structures (e.g. European Commission, 2017; *Agencia de Inovaçao*, 2015; Karo et al., 2017). The basic problem of combining centralized determination of targets and objectives with decentralized information and entrepreneurial processes appears to have been resolved reasonably well in many cases, while the strategy design process and commitment to entrepreneurial discovery have helped to increase knowledge through self-assessment and the discovery of potential and capacities (Kroll, 2016).

S3 has also contributed to two important shifts in attitude. First, it has helped to instil in policymakers a new policy mind-set of decentralization, public–private interactions, self-discovery and prioritization. Second, it has widened recognition that challenges to and opportunities for innovation are specific to each region, reflecting its history, existing specializations, and economic and social structures. By helping regions to recognize their differences and translate them into future competitive advantages, and providing tools and processes to handle such heterogeneity, the S3 approach has the potential to yield better results than the undifferentiated policy practices of the past.

### 7. Further development possibilities

The S3 approach, summarized in table 4.1, represents a potentially important shift in policy thinking, and its initial results appear promising. However, the process is much more demanding in terms of policymaking capability and monitoring competences than horizontal policies focusing on overall capabilities (Rodriguez Pose, et al., 2014; Karo et al., 2017; Morgan, 2016), and will not succeed without the necessary capabilities and commitment. This may be problematic for developing countries with limited organizational and implementation capacities. Within countries, too, sufficient scale and agglomeration of actors are essential determinants of the productivity of innovation activities, making a critical mass of innovation actors important, and thus advantaging larger systems such as urban centres.

International cooperation and collaboration are therefore critical to the wider success of the S3 approach. International development institutions should seek to ensure diffusion of the knowledge generated by European experiences, while managing and leading efforts to promote transferability of the concept to developing countries, keeping in mind that policy experiences in innovation can rarely be replicated in different economic and social environments without extensive adaptation. This is an essential point. While the European Union's extensive experience in S3 could allow it to play an important role in providing technical assistance and guidance, UNCTAD and other international agencies active in the field of STI for development could also consider launching programmes and initiatives in this area.

**Table 4.1 Policy design principles for smart specialization**

| Generic problems | Design principles |
|---|---|
| **Establishing priorities** | Level of granularity<br>Public–private interactions – transparency |
| **Developing a transformative activity** | Human capital – R&D sequencing<br>Integrated vision – vitality and inclusion<br>Tinbergen assignment |
| **Recognizing and implementing the implications of an experimental policy** | Entrepreneurial discovery<br>Flexibility and monitoring<br>Maximization of spillovers |

## D. PLATFORMS FOR ECONOMIC DISCOVERY

### 1. Technology, innovation and economic discovery

An important challenge for cooperation policy in STI is that innovations are much less readily transferrable than technologies (UNCTAD, 2014a). An innovation is not merely a new idea, but a new idea that is both adopted and materialized in some kind of process, product or service. Crucially, this involves a process of *economic discovery* through experimentation *in the economy*, which can only occur in the socioeconomic context where the technology is to be used (Foray and Phelps, 2011; Phelps, 2017). "The economy", in this context, is not limited to the business sphere, but also encompasses the social sector (social innovation) and the household level (common innovation).

The "knowledge factory" may thus be seen as comprising two "laboratories". As well as the scientific and engineering laboratory that produces transferrable technological knowledge, there is an economic laboratory – less studied, but equally universal – in which new products, processes, services and business models are imagined, allowing new economic opportunities to be identified and realized through innovation. The former produces knowledge about what does and does not work technically; the latter produces knowledge about what works economically, at what prices, and with what business models.

While it requires scientific and/or technological inputs, innovation is thus fundamentally an economic concept. It entails translating these inputs into products, processes and services, and discovering whether the market (and the society) is likely to adopt it, at what price, and through what kind of business model. Since such economic knowledge can only be produced where the innovation is to be adopted, it is also *indigenous*. Innovations only become global (i.e. new products or services are adopted globally) once their economic value has been proven across many economies.

Thus, technological revolutions, such as the current digital transition, are not merely bundles of new science and technologies, but above all explosions of economic knowledge – of start-up companies producing new knowledge about what does and does not work economically. But this discovery comes at a cost. While some companies may revolutionize industries by applying newly developed technologies and business models, most will fail.

Clearly, this process – of translating technological knowledge into economic knowledge – is not linear, but characterized by important feedback effects. Economic discovery often gives rise to a need for further technical improvements in products and processes; and many companies have their own R&D capacities and/or relationships with research partners. However, the economic laboratory is dominated by experts on business analysis, finance, marketing, etc., while scientists and engineers play a supporting role.

This perspective has major implications for innovation and cooperation policy. The concept of innovation capacity is often misunderstood, reflecting confusion between the two “laboratories”. Consequently, conventional indicators tend to measure science and technology rather than innovation in an economic sense, providing little information about the core of innovation capacities. This skews innovation and cooperation policy towards science and technology rather than innovation itself, neglecting the major challenge of supporting innovative entrepreneurs and financiers (Foray and Phelps, 2011). Important as science and technology cooperation undoubtedly is, this is a critical omission, as entrepreneurs and financiers are often deterred from innovative projects by the considerable risk and uncertainty they entail.

### 2. Platforms for economic discovery as a tool for innovation and cooperation policy

The objectives of STI policy and international cooperation are straightforward and well understood, relating to science and technology resources, human capital formation, public research organizations and universities, etc. The objectives of innovation policy and international cooperation to build innovation capacities, however, are more complex. The framework presented above highlights the importance of policies to support economic discovery and experimentation, including, for example, new business models, user experiences, marketing, iterations and the relationship between R&D and product experimentation. A key policy objective is to deliver a sufficient rate of return to economic discovery and innovation, in light of the information externalities and coordination failures that characterize them (Rodrik, 2004; Sabel, 2012).

To address this need, this report proposes an international cooperation effort focused on the establishment (as proposed in UNCTAD, 2014a) of local and regional platforms for economic discovery (PEDs) to rectify market and coordination failures. PEDs would operate by providing the capacities, capabilities and services lacking in developing countries to support local entrepreneurs in the economic discovery process. This might include, for example, supporting access to test markets, tailored financial solutions, specialized services to optimize feedback from economic discovery to innovation design, and development of and experimentation with new business models.

PEDs can be either generic, responding to any economic discovery problems of any firm in the regional economy, or thematic and specialized (Uotila et al., 2012), reflecting a region’s smart specialization (section D) and supporting those firms and entrepreneurs developing ideas and exploring opportunities in line with identified transformational activities. Such thematic platforms might include, for example:

(a) Clean solutions in wood energy production and logistical solutions to wood harvesting in a context of resource scarcity (e.g. in regions with a large or emerging forest industry);

(b) Decentralized renewable energy production (e.g. in regions with large rural areas and dispersed populations);

(c) Smart nano- and micro-technological solutions (e.g. in regions with an existing or emerging mechanical engineering sector); or

(d) Interactive communications for education and social media (to help young entrepreneurs in large urban systems).

In contrast with R&D subsidies, there would be no need to monitor and control access. Since the capabilities and infrastructures provided would be specific to the targeted field, only firms and entrepreneurs active in this field would have a reason to use them.

## 3. Designing platforms for economic discovery to achieve key innovation objectives

A PED operates in part as a coordination mechanism between the various capacities and resources present in the local innovation system (chapter III), to counter its limitations and deficiencies in providing the capabilities and resources needed to materialize and test new ideas. As well as assisting companies undertaking economic discovery processes directly, it also supports other actors that provide such assistance, including local R&D organizations (in universities and public research organizations), banks, specialized consulting companies and public agencies dealing with issues such as IPRs and trade.

PEDs can thus address two types of objectives. As well as supporting potential innovators through the provision of a range of services and resources, they can strengthen local innovation systems by promoting connections between firms and existing infrastructures and supporting agents with the potential to fulfil this role in the future. They thus have a dual capacity-building goal, towards companies and towards other actors in the innovation system.

Operationally, a PED would be composed of boards corresponding to the main functionalities of the economic discovery process – R&D, product development and certification, market analytics, trade and export, supply problems, human capital, finance, energy efficiency, etc. – based on an analysis of the key gaps in the innovation system. Each board would receive proposals from companies and entrepreneurs for innovation projects requiring resources or services within its specific area, either supporting companies directly or identifying and mobilizing elements of the innovation system to do so where appropriate.

While some of the services involved in the economic discovery process can be provided remotely, PEDs should be located inside the country concerned, to generate opportunities for observation, interaction and mutual learning. This is essential to the development of a local innovation system capable of providing the resources that local innovators need for economic discovery (Feldman and Kogler, 2010).

## 4. Platforms for economic discovery as an opportunity for international cooperation

Support to STI policies and strengthening of innovation capabilities tend not to be high priorities for bilateral and multilateral development cooperation actors. However, such support is essential to the rapid productivity improvement and structural economic change needed to achieve the Sustainable Development Goals.

PEDs could be a very effective tool to support local innovation and economic experimentation, to build local capacities, and to generate economic knowledge by promoting the materialization, improvement and adoption of innovative ideas where local innovation systems cannot provide all the capacities and capabilities required (DDC and SECO, 2015). Supporting the design and establishment of PEDs thus provides a practical avenue for development partners to refocus and strengthen international cooperation for innovation, extending its scope beyond its traditional aims and responding more effectively to particular local needs and conditions.

International support to PEDs is exemplified by the Cleaner Production Centres established in Colombia, Egypt, Morocco, Peru and Viet Nam as part of Switzerland's international cooperation policy (UNCTAD, 2014). These platforms offer a wide range of services related to innovation in the domain of clean technologies, providing technology-related engineering services, certifications, training and financial services, with particular support to the connections between local entrepreneurs and local banks (SECO, 2005). Similar approaches, entailing the establishment of collaborative supporting platforms to support discovery processes leading to the emergence of new activities, have been applied in Uruguay (Snoeck and Pittaluga, 2012), Argentina (Sanchez et al., 2012) and Colombia (Arbeldez et al., 2012).

# E. INNOVATIVE FINANCING

Recent changes in the global development discourse and technologies relevant to sustainable development have been mirrored in changes in financing. New modes of development finance have emerged, such as impact investment, crowdfunding and new types of bonds. These changes can make important contributions to financing the innovation needed to meet the Sustainable Development Goals, although they are unlikely to fill the financing gap – estimated at $2.5 trillion per annum[70] (UNCTAD, 2014b) – entirely.

## 1. Venture capital and business angels

In many countries, financing is dominated by banks. This has worked well for some countries (for example, Germany and Japan); but in many developing countries, risk aversion among commercial banks limits access to affordable financing by young, innovative firms and by SMEs. For young and innovative firms, which face relatively high risks, equity financing is often more appropriate (OECD, 2015a), as it allows the risk to be shared between the firm and investors, imposing no obligation to repay in the event of business failure. Two important forms of equity financing are venture capital and business angel finance.

Venture capital takes the form of equity investment in the pre-start-up, start-up and early growth stages of business development. It is widely recognized as an important source of equity finance for new technology-based firms and for supporting business innovation. While few venture capital schemes aim directly to create innovation as a key goal (Ramlogan and Rigby, 2013), increased venture capital activity has been found to increase patenting rates, an (imperfect) indicator of innovation (Kortum and Lerner, 2000).

Most venture capital comes from venture capital funds, which are generally owned and operated by firms (although some are in the public sector). Such funds provide professional management, monitoring firms' progress closely and intervening to improve their management and performance (though without necessarily providing expertise), and seek external investors, mainly institutional investors, to provide the bulk of the financing. They often aim to take advantage of firms with high growth potential, sometimes investing for up to ten years. The role of venture capitalists in monitoring the skill, effort and performance of entrepreneurs is recognized as providing a mechanism for overcoming information asymmetries (Gompers, 1995; Kaplan and Stromberg, 2003), a function not performed by other financing mechanisms – although this service may be reflected in relatively high fees for the general partners behind the fund (Kaplan and Stromberg, 2004).

Business angel finance is similar to venture capital, but less formally organized and generally smaller in scale. Angel investors have strong entrepreneurial skills and/or specialized knowledge of the relevant industry, and provide mentoring, business advice and access to networks in addition to financing (OECD, 2016a). Operating across a wide range of sectors, angel investors focus mainly on high-tech activities and remain focused on early-stage development, while venture capital increasingly also provides later-stage financing (Wilson and Silva, 2013; Wilson, 2015; OECD, 2015a; OECD, 2016a). While less recognized historically, business angels have reportedly received greater public support in OECD countries in recent years (OECD, 2016a).

While business angels generally invest in firms within close geographic proximity (OECD, 2015a), access to venture capital is becoming more widespread geographically as venture capital funds become increasingly international in nature (United Nations Economic Commission for Europe, 2009; OECD, 2011a) – although they are less likely to operate in small economies with few potential start-ups.

Where the basic conditions for building a successful local venture capital industry exist – notably significant high-tech activity and scope for the creation of a critical mass of start-ups – policies should support the emergence of venture capital financing. Support should also be provided to the development of active angel investment networks, which are likely to be viable at lower levels of existing high-tech activity.

Since both venture capital and business angels rely on a well-functioning entrepreneurial ecosystem, they can be promoted by support to upgrading of entrepreneurs (OECD, 2015a). One evaluation suggests that the systemic impact of publicly supported venture capital funds can be improved by complementing the provision of early-stage venture capital with measures to encourage the participation of more skilled and

70 Estimates of innovation financing typically cover only financing for business innovation. While sustainable development also requires financing for pro-poor, inclusive and social innovation and for policy support, data on these types of financing are scarce, and the evidence base is limited.

experienced entrepreneurs in key technology sectors (Jaaskelainen et al., 2007).

An obstacle to developing private sector venture capital is the absence of active stock exchanges that allow funds for future investment to be released by liquidating existing investments through initial public offerings (Black and Gilson, 1998). However, this problem can be eased through access to initial public offerings on foreign stock markets or regional exchanges, or by establishing secondary exchanges (or junior markets) for SME listings, which can also create an additional channel for risk financing. This has been done in several of the larger and more advanced Asian developing countries, such as China, India, Malaysia, the Philippines, Thailand and Viet Nam (OECD, 2015a).

Several developed and developing countries have successfully nurtured venture capital markets. The Inova programme in Brazil is recognized as a successful case of government support, developing both early and later stage financing through venture capital, business angels and seed financing. The Yozma programme in Israel has been another success story (box 4.4).

**Box 4.4 The Yozma programme for venture capital, Israel**

Israel's Yozma programme was launched in 1992, in response to the absence of a venture capital market, the Government's desire to encourage private financing for high-technology companies, and the failure of its programme of direct funding for R&D to produce the anticipated results.

Yozma had a government venture-capital fund of $100 million, which it invested in private venture capital funds ($80 million) and directly in high-tech companies ($20 million). Each project had to involve a respected international financial institution and a national one. Since the Government would invest up to 40 per cent of the funds required, $150 million of private capital was added to the $100 million of public funding. The resulting $250 million was invested in more than 200 newly established companies, while the number of venture capital funds and other private capital funds increased from 3 to more than 100. Multiplier effects were generated through the creation of new technology-based firms, which increased in number to around 3,000. Key factors in building a successful venture capital industry were the development of high-tech activities in the country and the scope for the creation of many new start-ups during the period when it was being promoted.

*Sources:* UNCTAD, 2013; Avnimelech and Teubal, 2008.

## 2. Impact investment

A significant development in the last decade has been the emergence of impact investment – targeted investment, generally made in private markets, that aims to address social or environmental problems while also providing a financial return at or below market rates, according to investors' strategic goals (Global Impact Investing Network, 2017b) (box 4.5). This includes community investment, directing capital to traditionally underserved individuals or communities, as well as financing for businesses with clear social or environmental purposes (Global Sustainable Investment Alliance, 2016). Major areas of investment include microfinance, energy, housing, financial services, health care, forestry and timber, food and agriculture, and education. A closely related concept is sustainable investment – selection and management of investments on the basis of environmental, social and/or governance factors as well as financial considerations.

Impact investment is not a separate asset class, and classification is complicated by the diversity of the types of funding and investors involved, which include investment funds, pension funds, insurance companies, banks, development finance institutions, foundations and individuals (Global Impact Investing Network, 2017a). However, impact investment is estimated to have increased from $101 billion in 2014 to $248 billion in 2016, and sustainable investment from $137 billion to $331 billion over the same period (Global Sustainable Investment Alliance, 2016), reflecting increasing interest by large institutional investors in establishing impact investment arms (possibly motivated by evidence that incorporating sustainability criteria in investments can improve financial performance) (OECD, 2017).

While impact investments span developed and developing countries, the most important destinations are Europe and North America (Global Sustainable Investment Alliance, 2016). Investments are concentrated mainly in mature private companies, followed by growth-stage investments and investments in mature companies traded on stock markets. While a significant number of impact investors are involved in the venture stage, seed capital and start-up investments, such investments are relatively small in value terms, particularly for seed capital and start-up investments (Global Impact Investing Network, 2017a).

As recommended at the May 2016 meetings of the United Nations Commission on Science and Technology for Development, impact investment merits further investigation as a potential avenue for funding STI for the Sustainable Development Goals, given its orientation towards social and environmental objectives (United Nations Commission on Science and Technology for Development, 2017:18). Of particular relevance are the analysis of the types of impact investments relevant to STI and their role in supporting the Sustainable Development Goals, the development of generally accepted metrics for measuring the impact of impact investments, and the implications for STI and other policies.

**Box 4.5 Impact investment funds aim to create social and environmental impact as well as financial return**

The Global Innovation Fund (GIF) was launched at the United Nations General Assembly meetings in 2014 as a collaboration between the United Kingdom's Department of International Development, the United States Agency for International Development, the Omidyar Network, the Swedish International Development Cooperation Agency, the Department for Foreign Affairs and Trade in Australia and the Department of Science and Technology in South Africa. GIF offers grants, loans (including convertible debt) and equity investments between $50,000 and $15 million to support innovations with the potential for social impact on a large scale, including new technologies, business models, policy practices and behavioural insights. GIF provides funding at three stages (pilot, test and scale) and is open to ideas from any sector and any country, provided the innovation targets those living on under $5 or, preferably, $2 a day.

One Acre Fund was awarded a grant of $15 million by GIF to develop tailor-made regional solutions for smallholders across six countries in sub-Saharan Africa. Its product innovations team runs hundreds of trials to find out what works at the local and regional level – which crop varieties grow best in certain areas, which products farmers are most likely to adopt based on local customs and markets, and how to make customized recommendations that fit farmers' varying needs. Once a trial is proven effective, GIF will support the scaling up process to reach as many farmers as possible. This GIF–One Acre Fund collaboration plans to create $37 million in new income for farmers over four years, and a further $65 million subsequently as new farming methods are adopted more widely, spreading the programme's impact.

Envirofit is a company founded in 2003, with collaborative linkages with the Colorado State University Engines and Energy Conversion Laboratory, to develop sustainable clean energy solutions to health and energy challenges. In 2007, Envirofit partnered with the Shell Foundation's Breathing Space Programme (an impact investor) to develop high-quality low-cost smart cooking stoves. Envirofit engineers designed and built what came to be known as the Rocket Stove. It is 50 per cent faster and 200 per cent more efficient than traditional cooking methods, while reducing smoke and toxic emissions by up to 80 per cent. More than 1.3 million stoves have been sold, improving the lives of more than 6.5 million people, and reducing carbon dioxide emissions. Building on this success, Envirofit has also introduced SmartGas, a pay-as-you-go service designed to provide access to affordable, safe and reliable LPG, by leveraging mobile phone and ICT technology.

*Source:* UNCTAD Secretariat

## 3. Crowdfunding

Crowdfunding has emerged as a mechanism for early-stage innovation financing in some developed countries in the past decade. It provides access to peer-to-peer lending through Internet-based electronic platforms, linking prospective investors with inventors, entrepreneurs and firms searching for financing. Examples include Kickstarter, launched in New York in 2009, with financing open to people from around the world; CircleUp, established in the United States in 2012, which takes equity stakes in companies with revenues of between $1 million and $10 million; and Social Mobile Local Lending, also established in the United States in 2012, which provides small loans for small businesses looking to expand (UNCTAD, 2013).

Crowdfunding is limited in scale, estimated at $16 billion in 2014 (OECD, 2016a), but appears to be growing rapidly (Wilson, 2015; OECD, 2015a, 2016). The majority of funding is for social and artistic causes and real estate activities rather than for-profit business activities (OECD, 2016a), mainly in the form of donations, rewards and pre-selling (or pre-ordering). However, credit crowdfunding is also common, and equity crowdfunding – the selling of securities through electronic platforms – is also now developing in Europe and the United States (OECD, 2015a).

The extent of crowdfunding in developing countries is unclear. While it could spread more widely with the development of appropriate regulation, it is likely to be constrained in some countries by limited ICT infrastructure and Internet connectivity and/or by issues of trust and security for online transactions. Before promoting crowdfunding, however, developing country Governments should consider the risks involved and establish appropriate regulatory positions. While crowdfunding has received close attention from regulators in some OECD countries in recent years, and has been subject to regulation and oversight in the European Union and the United States since 2013, it remains unregulated in most other countries. OECD regulators have generally been cautious in their approach due to concerns about transparency, investor protection and the potential for identity and payment data theft and cyberattacks (OECD, 2015a). Equity crowdfunding requires particular caution, due to the potential difficulties in evaluating investment projects through online platforms.

## 4. Innovation and technology funds

Innovation and technology funds designed specifically to finance R&D, technological development and innovation have become an important instrument for public funding of innovation in developing countries, particularly where venture capital and business angels are poorly developed and the financial system is dominated by commercial banks. Such funds may be financed by the public sector, international donors, development banks or the private sector, and may take the form of public–private partnerships. They may operate on a full subsidy basis or through co-financing, often matching funding put up by firms themselves. Projects may be evaluated and selected directly or through competition, with an increasing preference for the latter.

Innovation and technology funds have significant advantages over other instruments: they can be introduced relatively quickly; they allow flexibility in design and operation; they can target particular industries, activities or technologies in line with national priorities; and they can support strategic goals, such as promoting innovation in SMEs, entrepreneurial spirit and collaboration among enterprises and between universities and firms, making them complementary to approaches such as S3 and PEDs (sections C and D).

Innovation and technology funds have proved to be a popular instrument for financing R&D, technology and innovation, and have been adopted in countries such as Ghana, Rwanda, Peru and the Islamic Republic of Iran. In many other developing countries, however, particularly the least developed countries, small tax bases limit the extent to which fiscal revenue can finance the establishment of innovation funds to support private investments in innovation. This represents a case for the mobilization of international development funding to support innovative firms in developing countries. A specific proposal in this regard has been formulated by UNCTAD (2010).

However, the success of innovation and technology funds depends in part on the strength of the innovation systems within which firms operate. An evaluation of four Latin American innovation funds found that their effectiveness depended on the financing mechanisms used, non-financial constraints, the extent and quality of interaction between firms and academic institutions, and the characteristics of the target beneficiaries (Hall and Maffioli, 2008). As well as the design of the fund itself (box 4.6), other factors include the existence of an adequate base of inventors and entrepreneurs, and of knowledge-intensive activity in medium- and high-tech areas; the existence of basic science and technology infrastructure and basic R&D capacity; and the practice of collaboration and strength of collaborative linkages. Challenges also arise from asymmetric information and the need for experienced managers with industry knowledge and private sector experience. The Islamic Republic of Iran's Innovation and Prosperity Fund has sought to overcome these challenges by using brokers with good market knowledge in making project evaluations as a basis for investment decisions (UNCTAD, 2016).

**Box 4.6 Technology and innovation funds: Peru's Innovation, Science and Technology Fund**

Peru's Science and Technology Programme was established in 2006, based on a loan agreement between the Inter-American Development Bank and the Government of Peru. The first STI financing fund, (FINCyT I), operated between 2007 and 2012 with contributions from the Presidential Cabinet ($36 million), an Inter-American Development Bank loan ($25 million) and the State Treasury ($11 million). FINCyT I financed a variety of projects aimed at boosting the competitiveness of Peruvian enterprises, including:

(a) Projects on technological innovation in enterprises;

(b) Projects on scientific research and technological development in universities and research centres;

(c) Capacity-building activities for science and technology, including scholarships and internships; and

(d) Projects designed to strengthen and coordinate the national innovation system.

The programme financed 117 projects on entrepreneurial innovation and 76 on academic research, placing particular emphasis on the development of linkages between enterprises, universities and research centres. These projects have increased the number of enterprises innovating in products and collaborating with academic centres. In the five years before FINCyT was launched, Peruvian universities had applied for 11 patents; between 2007 and 2011 they applied for 33, 14 of them directly as a result of projects financed by FINCyT.

A variety of factors contributed to this success. First, the programme designed and introduced a modern management system, taking into account similar experiences in other countries in the region. Second, calls for tender were improved through a process of continuous learning. Third, in a country with a relatively complicated bureaucracy, the programme's independent structure enabled it to operate in shorter time frames better suited to promoting innovative activities. The provision of continuing support successfully stimulated and facilitated enterprises' participation in the programme.

Good practices adopted in FINCyT to increase its efficiency and effectiveness and ensure its independence included the following (Sagasti, 2012):

(a) A board of management with representatives from the public and private sectors and academia;

(b) Merit-based selection of enterprise and university projects through open public calls for proposals;

(c) Assessment of projects by independent experts, who recommended which should receive financial support;

(d) Financing in tranches, subject to partial results and proper execution, with no disbursements unless intermediate goals had been reached;

(e) Constantly monitoring of projects by FINCyT throughout the implementation phase, and of the programme by the Inter-American Development Bank; and

(f) Continuity of interventions over time, through a second phase of the project (FINCYT II).

*Sources:* UNCTAD, 2011b, 2013; Bazán and Sagasti, 2013; OECD, 2011b; Sagasti, 2012; and www.innovateperu.gob.pe (accessed 27 March 2018).

## 5. New types of bonds

While bonds are a traditional financing instrument, new types of bonds have been developed to target social or environmental benefits, including social impact bonds, development impact bonds and green bonds. **Social impact bonds** entail governments or other bodies entering into agreements with investors and social enterprises or non-profit organizations providing social services to finance projects aimed at achieving predefined measurable social outcomes (Social Finance, 2011; OECD, 2015b). A government agency or commissioning body makes payments to a bond-issuing organization or to investors once the agreed outcomes are achieved and independently verified (OECD, 2016b; Centre for Global Development, 2013).

**Development impact bonds** are a variation on this approach, aimed at bringing together multiple actors with different resources and expertise in projects for international development, to improve the quality, efficiency and impact of social programmes, by bridging the gaps between investors and opportunities and between financial returns and social benefits. The key difference from social impact bonds is that development impact bonds include donor agencies, which fund payments to private investors if verified development impacts have been achieved. They can bring additional benefits by helping to address the limitations of existing results-based mechanisms, for example, by providing project finance for service providers (particularly smaller organizations or enterprises) and/or governments to roll out interventions, thus shifting risks to private investors without compromising the focus on results (Center for Global Development, 2013).

**Green bonds**, pioneered by the European Investment Bank in 2007 followed by the World Bank in 2008, raise funds for projects to address climate change and other environmental issues in sectors such as renewable energy, low-carbon transport and water. Such bonds have been issued by several multilateral development banks, including the African Development Bank's Green Bond Programme, and the Asian Development Bank's Clean Energy Bonds. Interest in green bonds is growing rapidly, particularly in developing countries such as India and China, while Mexico and Brazil issued green bonds in December 2016 (International Renewable Energy Agency, 2017).

## F. INCUBATORS, ACCELERATORS AND TECHNOLOGY PARKS

Incubators, accelerators and technology parks can play a useful role, complementary to PEDs, and have been introduced by many developed and developing countries as a means of promoting economic growth and job creation. By bringing small technology businesses into one location, close to universities and research institutions, this is intended to promote exchanges of ideas, knowledge and learning, while facilitating access to skills, business services, mentors and value chains.

However, the results of such approaches have often been disappointing, and some applications have been abject failures. In many cases, absorption of the resulting innovation has been limited, the start-ups generated have been disconnected from local economies, and relatively few have become sustainable businesses. It has been argued that the impacts of such schemes have been exaggerated, giving rise to unrealistic expectations and "an overflow of attention and resources that cannot translate into 'magic' solutions to unemployment and other global challenges" (Mulas, 2016).

These disappointing results underline the importance of an enabling environment as the core of an effective innovation system, as discussed in chapter III. UNCTAD (2015) looks at some of the factors that influence the contribution of technology parks and incubators to the performance of the innovation systems in which they integrate. This includes policy coherence, financial sustainability, outreach, tenant selection and funding and capacity to assess innovation outcomes. Success depends both on "understanding and actively fostering the dynamics that can create sustainable and competitive start-ups over time" (Mulas, 2016), and on facilitating links between companies inside the incubators and dynamic companies outside them, without which they remain enclaves with limited economic impact.

**Box 4.7 Porto Alegre Sustainable Innovation Zone**

The Porto Alegre Sustainable Innovation Zone (ZISPOA) was the first step in the implementation of the Leapfrog Economic Strategy of Brazil's Rio Grande do Sul State, which aims to turn the state into Latin America's most sustainable and innovative region by 2030. By establishing a favourable location for international companies to do business, "Tecnopuc" in Porto Alegre attracted Microsoft, Dell, HP and ThoughtWorks, while the nearby "Tecnosinos" attracted SAP and HT Micron. The relationship with the university, good transport links and a favourable environment for the workforce appear to have been factors of attraction. The multinationals in the technology park are reported to have created an attractive address at which local companies want to be co-located. The university and the attractive city and region motivated the presence of international companies, which in turn attracted major local companies, initiating the development of an innovation ecosystem pipeline to generate start-ups. A key factor is the dynamism of the university, which provides a talent pool for a start-up culture and a basis for research relationships between businesses in the tech parks and the university.

A mix of major MNEs, local companies and small start-ups is needed for tech parks to thrive, and the two technology parks in Porto Alegre have incubators and other programmes to sponsor and support start-ups. The experience of ZISPOA contrasts with similar approaches in other developing countries, which have been based mainly on small local companies that have not been strong enough to provide a critical mass. Successful incubators, accelerators, and technology parks present a model based on the combination of the right university, the right strategic location for businesses, the right mix of technology companies in different fields, good infrastructure in energy and transport, and an attractive quality of life.

*Sources:* World Urban campaign, available at www.worldurbancampaign.org (accessed 26 March 2018); and Weiss and Nascimento (2016).

An important aspect of the latter issue is the focus of incubators. For example, it might be beneficial to focus on SMEs that provide technical, financial, organizational or marketing solutions to local exporters to global value chains, which are typically relatively dynamic, have a relatively secure cash flow, and face competitive pressures to stay on the cutting edge of technology and innovation; or else on local entrepreneurs seeking to apply globally available technologies to provide priority services (e.g. potable water or off-grid electricity) to local consumers affordably on a financially sustainable basis. These principles have been successfully applied in Brazil (box 4.7).

## G. SHAPING INTERNATIONAL COLLABORATIVE RESEARCH NETWORKS TO SERVICE THE SUSTAINABLE DEVELOPMENT GOALS

As discussed in chapter I, scientific research and the development of new technologies have a key role to play in the achievement of many of the Sustainable Development Goals. The International Council for Science identifies four priority areas for such research: food and agriculture, health, energy and oceans (ICSU, 2017). The achievement of highly ambitious global goals in widely differing local contexts requires the combination of the most advanced scientific capabilities with detailed local knowledge; and global collaboration offers great potential to contribute to this process, providing opportunities both to create new knowledge and to increase the impact of research by diffusing existing knowledge. However, it also brings new challenges, requiring a fundamental shift in policy approaches.

### 1. The growth of global research collaboration

While countries differ widely in the intensity of their international R&D activities, nearly all are engaged in science in some way, and most have international linkages. The scientific output of some emerging economies has grown considerably over recent decades. China, Brazil, India and the Republic of Korea increased the number of scientific papers produced annually 20-fold between 1981 and 2012, from 15,000 to more than 300,000 (Adams, 2013). Smaller, lower-income economies have also increased their scientific output faster than larger economies since the 1990s, by increasing investment in R&D, linking with high-performing countries, publishing on open-access online venues and using open data (Horlings and van den Besselaar, 2013).

Scientific research increasingly takes place among global teams of researchers, spanning national boundaries and often only loosely aligned with national goals (even where it draws on national funds), creating virtual networks that extend beyond individual institutions and disciplines. Between 1990 and 2015, the proportion of scientific papers with authors from more than one country rose from 10 per cent to 25 per cent (Wagner et al., 2015). Such articles have greater impact, as measured by citations, in all scientific fields: a positive relationship has been found between countries-per-paper and citations, possibly reflecting the particular engagement of prestigious researchers in international collaboration (Glänzel and Schubert, 2001).

While the greatest percentages of international activity are registered by developed countries such as the United Kingdom, Switzerland and Austria, developing countries' participation in such collaboration has increased over time, and countries such as Uruguay (67 per cent) and Thailand (38 per cent) also have high levels of international co-authorship. Most of the documented co-publications are academic, although the role of the business sector is becoming more important.

International projects might account for somewhere between 20 and 50 per cent of R&D spending,[71] including highly visible "big science" projects such as the European Organization for Nuclear Research ( box 4.8), ITER, and C-Band All Sky Survey; project funding by international bodies such as the European Commission's Framework Programmes; and projects funded in the framework of agreements between national funding agencies. Potentially more numerous are small-scale "bottom-up" projects, most notably in medicine and environmental science, where research is conducted by geographically dispersed teams – for

[71] This approximation is based on a broad understanding that coauthorships represent 80 per cent of all publications (Wuchty et al., 2007) and that 25 per cent of these are internationally coauthored (Wagner et al., 2015). This suggests that international collaborations may account for around 20 per cent of funded projects, and could be as much as 50 per cent of funded projects in some countries.

**Box 4.8 CERN as a model of international cooperation in science**

Cooperation at the European Organization for Nuclear Research (CERN) is based on the spirit of science for peace. Following the Second World War, European countries understood the need to join forces and pool resources to assure the development of fundamental physics on the continent. Today, CERN's expertise encompasses accelerators, detectors and computing, which have applications in many fields, including medical and biomedical technologies, aerospace, safety, environment, industry 4.0 and frontier technologies. At the height of the Cold War, CERN was the first Western institute to sign agreements with Soviet scientific institutes, and its SESAME project in Jordan brings together scientists in the Middle East to conduct fundamental research in physics. CERN, the only research centre to straddle the border of two countries, thus uses science as a universal language.

Openness is a core principle of CERN, which has helped to build the open Internet (development of the World Wide Web), adopted open source software early on, and pioneered open access initiatives. Commitment to open science goes hand in hand with the collaborative research culture in high-energy physics. Large projects at CERN typically benefit from in-kind contributions of member States, such as the construction of specific components back home and shipment to CERN for installation on site. CERN also has a dedicated Knowledge Transfer group that actively promotes open science by providing advice, support, training, networks and infrastructure to transfer know-how to industry, predominantly by the following means:

**Intellectual property (IP) management and licensing:** CERN's ownership of IP makes it possible to share knowledge with industry through contracts in the form of licenses, service consultancies or R&D collaborations.

**Open Source software and hardware:** Ever since releasing the World Wide Web software in 1994, CERN has provided access to software code, schematics for electronics, and mechanical designs to allow study, modification and redistribution of its technology to others. Among other products, CERN has released an open source software library management package, and published a freely available "Open Hardware Licence"

**Open data:** Since 2014, CERN has hosted an Open Data Portal, through which experimental data are released, together with detailed documentation, tutorials and visualization tools, under dedicated Open Science licenses.

**The CERN knowledge transfer fund**, launched in 2011, selects and finances innovative CERN projects with high potential for positive impact on society. Six or seven projects are selected each year, an average of CHF 90,000 awarded to each. The fund is partly supported by revenues from commercial agreements.

**Knowledge Exchange/CERN Knowledge Transfer Seminars:** CERN's Knowledge Transfer Group organizes and presents at key events of stakeholders including the high-energy physics community. Since 2016, CERN also organizes "Knowledge Transfer Seminars" at its premises to showcase the diversity of applications of its knowledge and technology.

**Entrepreneurship:** CERN has a network of nine business incubation centres across Europe, which assists entrepreneurs and small technology businesses to take its technologies and expertise to the market. CERN supports these companies through technical visits to its premises, technical consultancy or services, and preferential-rate licensing of CERN IP, while the business incubation centre manager provides office space, expertise, business support, access to local networks and finance.

**Education and training:** CERN offers a diverse range of education programmes for the general public, teachers and students.

*Sources:* CERN Knowledge Transfer (2013-2016 Editions);

https://home.cern/about/updates/2015/11/cern-speaks-un-about-laboratorys-cooperation-model; and http://cerncourier.com/cws/article/cern/56953 (both sites accessed 26 March 2018).

example, soil scientists comparing microbes across continents (Prober et al., 2014) and epidemiologists across the world comparing occurrences of Hepatitis E in high-income countries (Arends et al., 2014). Agricultural and biological sciences also have particularly high levels of international collaboration of this kind.

Many developing countries have increased R&D investment, increased training in STEM, and built the institutions and capabilities necessary to be involved in global collaborations. Emerging countries in particular – most notably China – have increased their participation in global science, in part by doubling their spending on R&D (UNESCO, 2010). This has expanded developing countries' capacity, both for locally relevant research for sustainable development and for the absorption and application of scientific knowledge. It has also narrowed, but not closed, the gap with the developed countries, which have also increased R&D spending. In 2013, 14 OECD member countries spent more than 2 per cent of their GDP on R&D, compared with five in 1981, six spending more than 3 per cent.[72] Among developing countries, according to the most recent data available from the UNESCO Institute of Statistics, only China and Singapore spent more than 2 per cent of GDP on R&D, and none reached 3 per cent.[73]

## 2. Drivers of global collaboration

Over the past 20 years, increased R&D spending and institutional strengthening have led to an extension of scientific research far beyond the few countries in which it was previously concentrated. This has been an important driver of cross-border collaboration in scientific research. Other important factors have been:

(a) Collaboration: Coordination of research towards specific questions or goals through cooperation, formation of teams or sharing resources, generally based on "bottom-up" self-organization;

(b) Global linkages: Emerging from connections among people and information-sharing, facilitated by easier and cheaper travel and electronic communications; and

(c) Open data: Sharing of research data in real time rather than awaiting publication, through searchable open-access databases such as the Database of Genomic Structural Variation (dbVar) maintained by the United States National Library of Medicine.

Open data sources (box 4.9) can contribute significantly to the Sustainable Development Goals, making open access a key policy issue in the 2030 Agenda for Sustainable Development. Previously, journal articles were available only to those with access to university libraries, and time lags in publication meant that the most recent findings were two years old, while accessing data from distant places required expensive and time-consuming travel. This has changed dramatically. By 2013, 50 per cent of scientific journal articles were available through open access venues on the Internet (Archambault et al., 2014), 12 per cent of these appearing as soon as they passed peer review, and 35 per cent after an embargo period following publication. Prepublication drafts are also increasingly available through open repositories such as arXiv.org (accessed 26 March 2018).

72 Japan, Germany, Sweden, the United Kingdom and the United States were above 2 per cent in 1981. In 2013, Australia, Austria, Belgium, France, Germany, Switzerland and the United States were between 2 and 3 per cent, and Denmark, Finland, Israel, Japan, the Republic of Korea and Sweden were above 3 per cent.

73 Available at uis.unesco.org/apps/visualisations/research-and-development-spending/ (accessed 26 March 2018).

**Box 4.9 What is "open" in global science?**

There are several interrelated terms relating to "openness" in global science. Definitions of key terms are provided below – although it is important to note that definitions and contexts evolve over time.

(a) Open science: Making scientific outputs and processes, including publications, models and data sets, publicly accessible;

(b) Open innovation: Inflows and outflows of knowledge, beyond the walls of a laboratory, firm or team, which can accelerate innovation and enhance consumer and user satisfaction with final products;

(c) Open data: Publicly available and accessible data that can be universally and readily found and redistributed free of charge in ways that enhance veracity and research efficiency;

(d) Open access: A mechanism by which research papers, books, data sets and other educational or research materials are made available to users without charge;

(e) Open repositories: Online stores of scholarly research results that anyone can inspect and comment on, usually in particular disciplines and moderated by experts;

(f) Open source software: Computer source code that anyone can inspect, modify, and enhance.

Open access policy is institutional support, often by government, university, or non-profit entities, for unrestricted access to research and underlying data as part of the mission to enhance public benefit and translation to application.

*Source:* Open Scholarship Initiative, available at http://osinitiative.org/ (accessed 26 March 2018).

Large-scale open databases have allowed similarly radical changes in the scope, complexity and accessibility of stored information such as raw scientific data and information on standards.[74] Many formerly proprietary scientific databases are also now available online, making research on the Zika virus, for example, available in real time during the crisis. This shift of information and knowledge from scarcity to abundance is little short of revolutionary.

## 3. Implications of global collaboration for STI governance and policy

R&D generally involves four sectors – business, government, academia and private non-profits – in complementary roles. Typically, governments fund research; businesses fund and conduct research; academia conducts research and trains practitioners; and private non-profits play all these roles on a smaller scale (table 4.2). In OECD countries, business on average provides 60 per cent of R&D funding and conducts nearly 70 per cent of R&D, the relative importance of public funding having declined in recent years.[75] While the public sector plays a substantially greater role in developing countries, and non-governmental actors (e.g. philanthropic organizations and advocacy groups) are increasingly significant in what is funded and researched, the primary role of business in national R&D capabilities makes attracting private sector support an important part of STI policy.

**Table 4.2 Sectoral roles in R&D**

| | Fund R&D | Perform R&D | Train practitioners |
|---|---|---|---|
| Government | Secondary | Secondary | *Tertiary* |
| Business | **Primary** | **Primary** | *Tertiary* |
| Academia | *Tertiary* | **Primary** | **Primary** |
| Private–non-profit | Secondary | Secondary | *Tertiary* |

The involvement of multiple sectors complicates policy planning. While governments generally set policy and establish goals, policymakers have only indirect influence on business and academic researchers. Research funded and/or conducted primarily by business, whether local or international, can be especially challenging in this regard. A further complication is that most research is effectively invisible to national agencies until its results are published.

74 ASTM International is one of the world's largest international standards-developing organizations. The organization has 30,000 members from 140 countries.

75 OECD Main Science and Technology Indicators, 2015.

The increasing globalization of research adds yet a further dimension of complexity. International connections among researchers affect the direction of research and the distribution of tasks in ways that may not be apparent to policymakers. It also makes the locus of research activities and of scientific knowledge less clear than in the past, as it is more difficult to identify centres of knowledge. The governance of national resources within a global system is complicated by the increasing mobility of researchers and by reliance on data, samples and cases collected from around the world and on equipment in distant places.

Global networks are inherently challenging to govern or direct towards any set of goals; but understanding and learning to use them to shift the agenda can have positive outcomes for the Sustainable Development Goals.

The new context requires different policy approaches from those used to promote and manage R&D in the twentieth century, which treated science and technology primarily as national assets. Four features of policy are particularly relevant:

(a) Viewing knowledge as an abundant rather than a scarce resource, sharing fully in collaborative R&D and disseminating knowledge openly;

(b) Enhancing local and regional capacities to absorb knowledge, focusing on building scalable teams on key topics with local relevance;

(c) Storing information for sharing, access and comment; and

(d) Ensuring adequate credit to those contributing knowledge to shared resources.

Governments need to move beyond simply funding and managing R&D to influencing networks, in order to foster participation in global collaborations, to guide them towards research of value to sustainable development, and to maximize its development impact. This requires an understanding of how such networks are formed and organized, the norms and dynamics that drive them, the motivations of those involved, and the internal control mechanisms of sharing and rewards underlying global collaboration (box 4.10).

The norms of the global research system are common to networks, involving reciprocity, sharing and influence. Each party to a collaboration brings something of value to the process, whether an interesting research question, useful data, time for coordination, or reputation and influence. Research managers can create conditions for such reciprocity by making it easier to identify common issues,

**Box 4.10 Network operations and incentives**

Unlike organizations with a strict hierarchy of authority, where behaviour is directed and performance is rewarded, networks operate by rules that reward reciprocity. Members of a common network exchange resources as the "cost" of being in the network, in the expectation of mutual benefits. The "reward" is the good received and the added social reputation gained by good citizenship. New members are included to the extent that they offer "goods", and will be excluded if they are seen as "hoarding" goods.

Most network connections in science begin face-to-face at conferences or meetings. Being "prepared to network" means giving forethought to the "goods" that one has to offer to potential partners. Such goods include interesting data, important research questions, time to work on a project, depth of knowledge in a subject, student collaborators, access to unique resources, and funding. Networks can form as readily between more experienced and inexperienced participants as between social equals, in part because unequal pairings may be highly complementary. Pairing between social equivalents can be difficult if their fields of research are too similar, as this can create competitive tensions.

Networking requires more time than projects with a high degree of hierarchy and discipline; the greater the intellectual distance between members, the more time is needed to develop a common nomenclature. Over time, however, teams with diverse members are shown to be more productive and creative than homogeneous teams.

*Source:* UNCTAD Secretariat

providing examples of data-sharing protocols, and crafting memoranda of understanding to facilitate in-kind contributions and cross-border movements of equipment, samples, etc. Bundling such elements into project proposals can enhance the attractiveness of collaborative activities.

The implications of global collaboration in research transcend national boundaries. The international community has adopted global goals; global research has an essential role in their achievement; and the global knowledge commons are fundamental to this research. Realizing this potential requires national policies to be complemented by global governance the process of seeking to manage or influence relationships that transcend national frontiers, performing a role analogous to that of governments at the national level, but without sovereign authority. The United Nations Commission on Science and Technology for Development has been encouraged by the Economic and Social Council to act as a forum for strategic planning and foresight about critical trends in STI, and to strengthen and revitalize global STI partnerships for sustainable development.[76] It thus provides a global platform for coordination to support more focused efforts on research collaboration. This is particularly important considering the gaps in research capabilities identified in chapter II, and their implications for the ability of many countries to undertake technological horizon scanning, foresight and risk assessment.

[76] See Economic and Social Council resolution 2017/22.

However, there is no single organization with a mandate for global governance of science, and national governments remain the primary locus of STI policy and investment. The recommendations in this section should therefore be interpreted as applying to intergovernmental organizations at the global level as much as to national governments.

Aligning guidelines for national governments through international organizations, possibly focusing on a small number of specific scientific goals initially, may thus contribute to focusing science on the Sustainable Development Goals. A key role of the international community is financial and technical support to capacity-building in developing countries, especially LDCs, through international organizations, multilateral and bilateral agencies and South–South cooperation, to increase their ability both to participate in Sustainable Development Goals-oriented research and to absorb and apply the knowledge it generates effectively. International organizations could also help to build on existing open access databases and other online resources, both as an input to Sustainable Development Goals-related research and as an outlet for its results, particularly by taking a leadership role in the establishment of quality measures and monitoring.

## 4. Fostering participation in global research collaboration towards the Sustainable Development Goals

Funding is a key method of guiding the direction of research. Targeting research funding towards Sustainable Development Goals-related projects can influence outputs and outcomes, as can inclusion in notices soliciting bids for funding of statements about support for such collaborations. Requiring involvement of researchers from relevant developing countries in Sustainable Development Goals-related research collaborations could help to ensure that research addresses the problems such countries face, and fully reflects local contexts, as well as helping to build capacity. Use could also be made of surveys, textual analysis and/or network analysis tools to locate connections offering opportunities for fruitful collaboration.

Connections among people are central to global research collaborations, but such connections are formed through an amorphous process of self-organization, which is not conducive to policy intervention. Most collaborations begin through peer-to-peer relationships established by personal contact and networking – for example, at conferences and through research websites; institution–to–institution or intergovernmental agreements have at most an indirect role in this regard.

Convening international events related to particular aspects of the Sustainable Development Goals, bringing together leading global and local scientists, thus helps to foster interpersonal contact among researchers with relevant interests. Support for travel and convening can also play an important role. Augmenting research grants with supplementary funding for travel and communications targeted to collaborative projects including partners from developing countries, a policy operated by the United States National Science Foundation and by the European Commission for more than 30 years, can thus make a major contribution to fostering global collaboration. Training abroad can also help to strengthen international linkages more broadly – particularly where those concerned return to their countries of origin, also increasing domestic capacity.

More than research quality, novelty or efficiency, the underlying dynamic pushing researchers towards global collaboration appears to be enhanced opportunities for recognition and reward. Cooperation around specific goals might therefore be incentivized by accolades such as prizes and awards – especially at the international level – naming rights, invited lectures and named chairs. The opportunity to participate in leading-edge research, particularly where a breakthrough is anticipated, is a particular driver, as are opportunities to collaborate with prominent researchers.

Some of the science to address the Sustainable Development Goals is already available, or research is underway (Lubchenco, 2015). The relevance of research can be enhanced by mapping existing scientific knowledge and current research against local needs, to target research and avoid redundancy. This involves connections with citizens as well as scientists, e.g. through social media such as Zooniverse, to build links between existing scientific work and future needs. Scanning globally for technology and ideas, bringing together local engineers and business people, assistance to regional planning and building communications options to gather ideas can also make an important contribution.

Establishing national platforms for collaborators on issues related to the Sustainable Development Goals might also provide a means of nudging networks towards relevant research, particularly if such platforms provide enhanced functionality for researchers, facilitate networking with others working on related projects, and are linked to open access online publications. Identifying particular local and regional problems and framing them in such a way as to attract international research attention may help to foster locally relevant collaborations.

## 5. Maximizing development impact

If global research collaboration is to contribute effectively to development, the knowledge generated must be integrated at the local level. This requires the development of sufficient absorptive capacity to retain knowledge locally and apply it to local and regional problems. It is therefore important to ensure that the globalization of scientific research does not impoverish the "local loop" of research diffusion by distracting efforts from teaching and cooperation.

Local planning is also needed to ensure that the necessary capacity is available. This requires assessing local resources and using gap analysis to identify opportunities and determine where additional investment is needed, by:

(a) Assessing technical know-how and human resources, by examining colleges and technical schools that are training engineers, the workforce employed in technical firms, and participation in scientific and technical societies;

(b) Appraising institutions by subject area (e.g. medical, environmental and material);

(c) Identifying and strengthening methods of formal and informal communication; and

(d) Making local and informal knowledge available through communications channels.

International support to capacity-building plays a key role. Researchers and funders should commit to building scientific capacity in developing countries to help improve their ability to conduct, access, verify and use the best science, and to ensure that they can contribute to global scientific debates and develop locally appropriate solutions to global problems.

## H. CONCLUSIONS

Recent decades have seen a combination of accelerating technological change with ever greater potential and more far-reaching implications, and progressively more comprehensive and ambitious global goals. These changes have been reflected in several new concepts and approaches of relevance to harnessing STI for sustainable development.

The extraordinary ambition of the 2030 Agenda for Sustainable Development means that full use will need to be made of all the available tools if the Sustainable Development Goals are to be achieved. Given the central role of innovation in the structural economic transformation that is indispensable for sustainable development, STI must be an essential part of this process.

Fundamental as it is, structural transformation cannot be the only goal of STI policy for development in the pursuit of the Sustainable Development Goals. New approaches to innovation, such as those described in this report, which are in no small part enabled by digital technologies, should support an aspiration in STI policymakers to orient the direction of change and innovation towards more inclusive and sustainable outcomes. Most crucially, a concerted effort is needed to build technological capabilities and to support all forms of innovation – technological and non-technological, entrepreneurial, social, institutional – in developing countries. This is an effort that includes the mobilization of stakeholders at the national level, but that also requires the full realization at the international level of the scale of the changes that frontier technologies will introduce in human activity. The unprecedented divides that could result create an ethical imperative to ensure that no one is left outside this emerging new world. The least developed countries, in particular, should receive international support to build the capabilities and create the enabling environment for frontier technologies necessary to deliver on their promise.

The Technology Facilitation Mechanism established in the 2030 Agenda for Sustainable Development could act as an open platform for stakeholders to create awareness, connect innovators with those confronted with development challenges that STI can solve, promote policy learning and mobilize the resources of the United Nations system. The Technology Bank for the Least Developed Countries, which adopted its first operational plans at the end of 2017, provides an instrument to channel much needed resources to support LDCs' access to knowledge and technologies.

UNCTAD and the UN Commission for Science and Technology for Development, in addition to supporting these processes and contributing to relevant capacity building, have an international policy role to play improving the understanding of the deep and multidimensional implications of technology, and contributing to international dialogues dealing with the serious questions that frontier technologies raise about issues such as ethics, the environment, economic stability and social cohesion. Only through such dialogues can useful answers be found to the challenge of harnessing technology for the achievement of sustainable and inclusive development.

**Box 4.11 Key messages and conclusions**

(a) The convergence across all technologies due to digitalization has given rise to innovative approaches to accessing and adopting technologies.

(b) Technological leapfrogging can bring large benefits where it is possible. Leapfrogging by adopting technologies developed elsewhere is easier than leapfrogging through the development of new technologies.

(c) Policy-makers should seek to understand the scope for leapfrogging in specific technologies and sectors, which may vary widely.

(d) Several new approaches to innovation offer potential to promote sustainable development, including pro-poor, inclusive, frugal, grass-roots and social innovation.

(e) Smart specialization might be adapted by developing countries, particularly those with robust policy-making capacity, as an approach to exploring what activities can be developed in particular locations.

(f) Successful innovation requires access to technology to be translated, through economic discovery, into innovations that are commercially successful or solve problems in non-commercial settings. Platforms for economic discovery can help to achieve this, and could form a basis for international cooperation.

(g) Innovative financing mechanisms, such as innovation and technology funds, new types of bonds and crowdfunding, can help to channel funding towards innovation, as can policies to promote venture capital, business angel finance and impact investment. International development funding has a role in supporting innovative firms through innovation funds, particularly in LDCs.

(h) Incubators, accelerators and technology parks can stimulate the creation of dynamic innovation zones, but results are often disappointing when they are not part of a coherent policy framework and integrated in a local innovation system.

(i) Governments need to move beyond funding and managing R&D to influencing networks, to foster developing country participation in global research collaboration and maximize its development impact.

(j) Targeting research funding towards Sustainable Development Goals-related projects can help push research into areas of importance to sustainable development. Cooperation around specific goals might be incentivized by prizes and awards.

(k) Some of the science to address the Sustainable Development Goals is already available, or research is underway. The relevance of research can be enhanced by mapping existing scientific knowledge and current research against local needs.

(l) A concerted effort at the national and international levels is needed to build technological capabilities and to support all forms of innovation – technological and non-technological, entrepreneurial, social, institutional – in developing countries.

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