UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT

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TECHNOLOGY AND INNOVATION REPORT 2021

Catching technological waves

Innovation with equity

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NOTE

Within the UNCTAD Division on Technology and Logistics, the STI Policy Section carries out policy-oriented analytical work on the impact of innovation and new and emerging technologies on sustainable development, with a particular focus on the opportunities and challenges for developing countries. It is responsible for the *Technology and Innovation Report*, which seeks to address issues in science, technology and innovation that are topical and important for developing countries, and to do so in a comprehensive way with an emphasis on policy-relevant analysis and conclusions. The STI Policy Section supports the integration of STI in national development strategies and in building up STI policy-making capacity in developing countries; a major instrument in this area is the programme of Science, Technology and Innovation Policy Reviews. The section also serves as the core secretariat of the United Nations Commission on Science and Technology for Development (CSTD).

In this report, the terms country/economy refer, as appropriate, to territories or areas. The designations of country groups are intended solely for statistical or analytical convenience and do not necessarily express a judgement about the stage of development reached by a particular country or area in the development process. Unless otherwise indicated, the major country groupings used in this report follow the classification of the United Nations Statistical Office. These are:

Developed countries: the member countries of the Organisation for Economic Co-operation and Development (OECD) (other than Chile, Mexico, the Republic of Korea and Turkey), plus the European Union member countries that are not OECD members (Bulgaria, Croatia, Cyprus, Lithuania, Malta and Romania), plus Andorra, Liechtenstein, Monaco and San Marino. *Countries with economies in transition* refers to those of South-East Europe and the Commonwealth of Independent States. *Developing economies*, in general, are all the economies that are not specified above. For statistical purposes, the data for China do not include those for the Hong Kong Special Administrative Region of China (Hong Kong, China), Macao Special Administrative Region of China (Macao, China) or Taiwan Province of China. An Excel file with the main country groupings used can be downloaded from UNCTADstat at: http://unctadstat.unctad.org/EN/Classifications.html.

References to sub-Saharan Africa include South Africa unless otherwise indicated.

References in the text to the United States are to the United States of America and those to the United Kingdom are to the United Kingdom of Great Britain and Northern Ireland.

The term “dollar” ($) refers to United States dollar, unless otherwise stated.

The term “billion” signifies 1,000 million.

Annual rates of growth and change refer to compound rates.

Use of a dash (–) between dates representing years, such as 1988–1990, signifies the full period involved, including the initial and final years.

An oblique stroke (/) between two years, such as 2000/01, signifies a fiscal or crop year.

A dot (.) in a table indicates that the item is not applicable.

Two dots (..) in a table indicate that the data are not available, or are not separately reported.

A dash (–) or a zero (0) in a table indicates that the amount is nil or negligible.

Decimals and percentages do not necessarily add up to totals because of rounding.

FOREWORD

Recent developments in frontier technologies, including artificial intelligence, robotics and biotechnology, have shown tremendous potential for sustainable development. Yet, they also risk increasing inequalities by exacerbating and creating new digital divides between the technology haves and have-nots. The COVID-19 pandemic has further exposed this dichotomy. Technology has been a critical tool for addressing the spread of the disease, but not everyone has equal access to the benefits.

It is time to ask how we can take full profit from the current technological revolution to reduce gaps that hold back truly inclusive and sustainable development. The UNCTAD Technology and Innovation Report 2021 examines the likelihood of frontier technologies widening existing inequalities and creating new ones. It also addresses the national and international policies, instruments and institutional reforms that are needed to create a more equal world of opportunity for all, leaving no one behind.

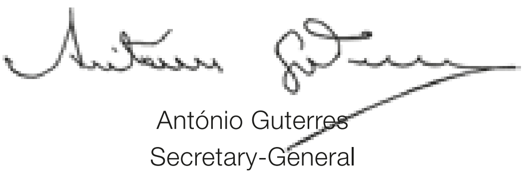
The report shows that frontier technologies already represent a $350 billion market, which could grow to $3.2 trillion by 2025. This offers great opportunities for those ready to catch this technological wave. But many countries, especially the least developed and those in sub-Saharan Africa, are unprepared to equitably use, adopt and adapt to the ongoing technological revolution. This could have serious implications for achieving the Sustainable Development Goals.

The Technology and Innovation Report 2021 urges all developing nations to prepare for a period of deep and rapid technological change that will profoundly affect markets and societies. All countries will need to pursue science, technology and innovation policies appropriate to their development stage and economic, social and environmental conditions. This requires strengthening and aligning Science, Technology and Innovation systems and industrial policies, building digital skills among students and the workforce, and closing digital divides. Governments should also enhance social protection and ease workforce transitions to deal with the potential negative consequences of frontier technologies on the job market.

The report also calls for strengthened international cooperation to build innovation capacities in developing countries, facilitate technology transfer, increase women's participation in digital sectors, conduct technological assessments and promote an inclusive debate on the impact of frontier technologies on sustainable development.

A key takeaway from the report is that technologies are not deterministic. We can harness their potential for the common good, and we have an obligation to do so. That is why I launched a Strategy on New Technologies in September 2018 to guide the United Nations system on how new technologies can and must be used to accelerate the achievement of the Sustainable Development Goals and the realization of the promise of the United Nations Charter and the Universal Declaration of Human Rights.

New technologies hold the promise of the future, from climate action and better health to more democratic and inclusive societies. As this report highlights, the guiding principle of the 2030 Agenda for Sustainable Development to leave no one behind provides a compelling incentive for harnessing frontier technologies for sustainable development.
Let us use them wisely, for the benefit of all.



António Guterres
Secretary-General
United Nations

PREFACE

The Technology and Innovation Report 2021 critically examines the possibility of frontier technologies such as AI, robotics and gene-editing widening existing inequalities and creating new ones. The debate about the relationship between technological change and inequalities has a long tradition in development studies. However, the broad reach, the seemingly unlimited and tight integration of these new technologies through digitalization and connectivity, and the rapid pace of technological change have put in doubt the relevance of the experiences of previous technological transformations to inform the current policy debate.

Frontier technologies can bring enormous benefits to the lives of poor people. Prospects are immense in agriculture, health, education, energy and other areas of development. There are numerous examples on successfully mobilizing frontier technologies. However, many of these technology deployment remains at pilot level. This Report discusses how to scale them up, how to bring their benefits to the poor, what government interventions and business models work, what good practices and lessons are there, and what the missing links are.

There is also a concern that automation, AI, robotics will destroy jobs and with that the dream of poor people in developing countries to get out of poverty. There is a fear that the chasm between haves and have nots would widen, while benefits are captured by a few with skills and capital. This Report discusses the impact of these technologies on labour markets and how to prepare the work force to benefit from the frontier technologies and minimize the risks.

The Report focuses on low and middle-income developing countries and least developed countries, as well as on the most vulnerable segments of societies, while providing discussion on the effects on high-income countries as parts of the broader context and major drivers of frontier technologies.

The Report argues that frontier technologies are essential for sustainable development, but they also could accentuate initial inequalities. It is up to policies to reduce this risk and make frontier technologies contribute to increasing equality. Low- and middle-income developing countries and the least developing countries cannot afford to miss the new wave of rapid technological change.

Harnessing this new technological revolution will require countries to promote the use, adoption and adaptation of frontier technologies. A balanced approach building a robust industrial base and promoting frontier technologies is a must for success in the twenty-first century.

Mukhisa Kituyi
Secretary-General
United Nations Conference on Trade and Development

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OVERVIEW

Human development in recent decades has been accompanied by rapid changes in technology and an increasing proliferation of digitized devices and services. And the pace of change seems likely to accelerate as a result of "frontier technologies" such as artificial intelligence (AI), robotics, biotechnology, and nanotechnology.

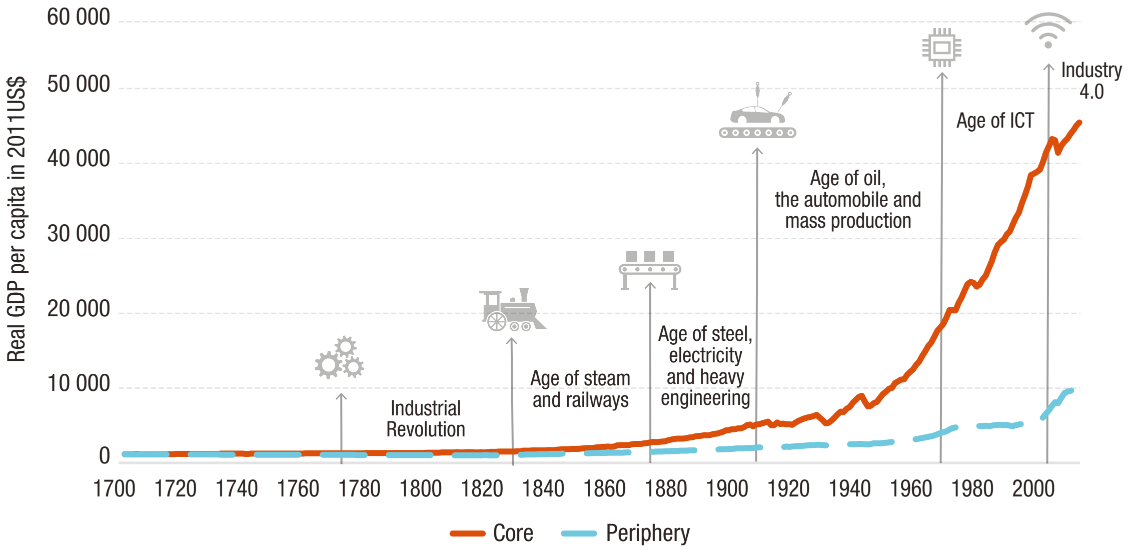
These technologies have already brought enormous benefits – dramatically highlighted in 2020 by the accelerated development of coronavirus vaccines. But rapid advances can have serious downsides if they outpace the ability of societies to adapt. There are fears, for example, that jobs are disappearing as more economic activity is automated, and that social media is exacerbating divisions, anxiety and doubt. Overall, there are concerns that frontier technologies will further widen inequalities, or create new ones.

Most of these issues have been voiced in developed countries. But the implications could be even more serious for developing countries – if poor communities and countries are either overwhelmed or simply left behind. This report considers how developing countries can catch the wave of frontier technologies, balancing innovation with equity in pursuit of the Sustainable Development Goals.

1. CATCHING THE WAVES

We live in an age of dramatic technological advances, mostly concentrated in developed countries, but the great divides between countries that we see today started with the onset of the first industrial revolution. At that point most people were equally poor and the gaps in per capita income between countries were much smaller (Figure 1). Then with waves of technological change, Western Europe and its offshoots – Australia, Canada, New Zealand, and the United States – along with Japan, pulled ahead. Most other countries remained on the periphery. Every wave of progress was associated with sharper inequality between countries – with widening disparities in access to products, social services and public goods – from education to health, from ICT infrastructure to electrification. Nevertheless, a few countries, notably in East Asia, were subsequently able to catch up through technological learning, imitation and innovation.

Figure 1
Technological change and inequality through the ages



Source: UNCTAD, based on data from Maddison Project Database, version 2018, Bolt et al. (2018), Perez (2002), and Schwab (2013).

Notes: "Core" corresponds to Western Europe and its offshoots (Australia, Canada, New Zealand and the United States) with Japan. "Periphery" corresponds to the world, excluding the "core" countries.

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Prosperity with inequality

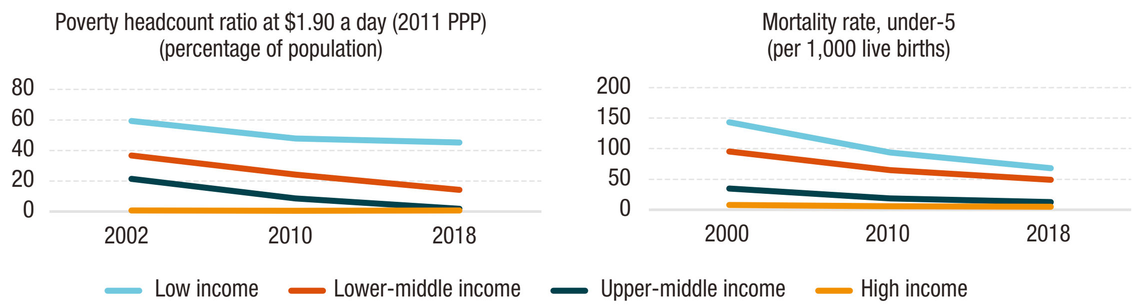
During recent decades of digitization, the world has seen growing prosperity. People on average are living longer and healthier lives. Rapid economic growth in emerging economies has fuelled the rise of a global middle class. Nevertheless, there is persistent poverty, and rising inequality. Wealth is highly concentrated, and there are also large disparities in income-earning opportunities, as well as in standards of education and health. These imbalances constrain economic growth and human development while heightening vulnerability, whether to pandemics, or economic crises or climate change – and can soon destabilize societies.

Multifaceted inequalities

Inequality is a multifaceted concept related to differences in outcomes and opportunities between individuals, groups or countries. These differences can arise along any dimension of development – social, economic or environmental. Inequality of outcomes and opportunities are closely intertwined. The outcomes for one generation affect the opportunities for the next – resulting in intergenerational transmission of inequalities.

As indicated in Figure 2, there are still large inequalities between countries. People in low- and lower-middle-income countries, on average, suffer from much higher levels of poverty and deprivation when compared with people in upper-middle- and high-income countries.

Figure 2
Gaps between country groups, selected SDG indicators



Source: UNCTAD based on data from the World Bank.

Wide income gaps

Many of the inequalities correlate with levels of income. In the past 10 to 15 years, global income inequality has decreased, mainly because large developing countries, mostly in Asia and notably China, have grown faster and started to catch up. However, achievements in global equality are threatened by rising disparities within countries. Over the past 40 years, within-country inequality has increased not only in some developed countries such as the United States, and in Europe, but also in developing countries such as China and India.

Given that within-country inequality is rising, while the disparities between countries are falling, what is the net effect? To answer that question, we must consider the contribution of both types of inequality to global inequality. Estimates suggest that between-country inequality now dominates. Between 1820, the onset of the industrial revolution, and 2002, the contribution of between-country inequality to global inequality rose from 28 to 85 per cent. In other words, in 1820, global income inequality was driven by class divides within countries. Now it is driven more by the lottery of birthplace: a person born in a poor country suffers a 'citizen penalty'.[1]

Since it is the dominant component, the recent relative reduction in inequalities between countries may be a cause for celebration. But it should disguise the fact that in absolute terms the gap between developed and developing countries has never been higher and continues to increase (Figure 3).

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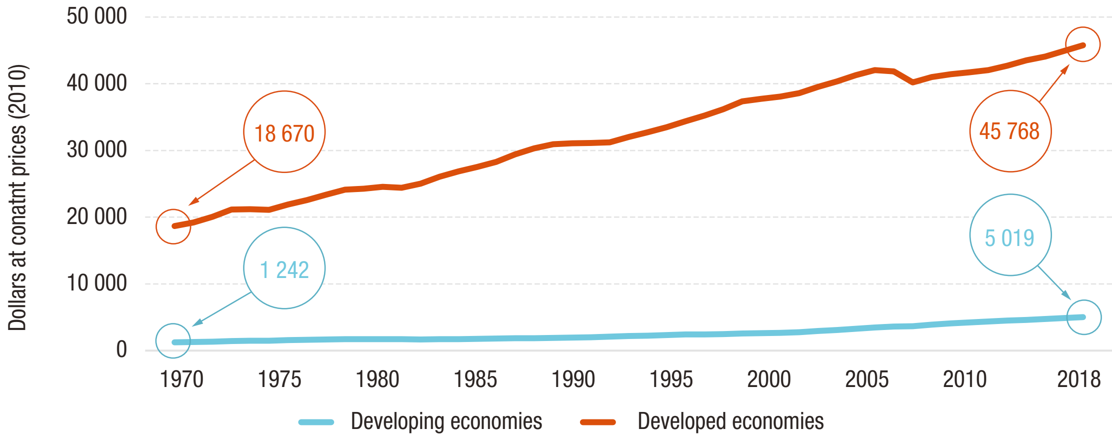
Figure 3
Average GDP per capita in developing and developed economies, 1970-2018



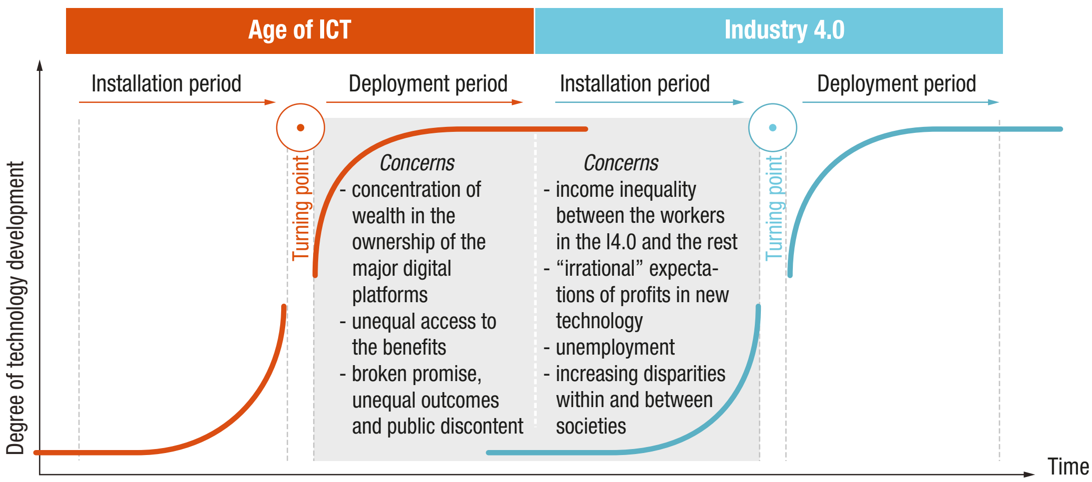
Source: UNCTAD calculations based on UNCTADstat.

Two-phase revolutions

There is no consensus on the dynamics of economic inequality – which is affected by many factors, such as war and epidemics, as well as by political processes influenced by power struggles and ideologies. Globalization and technological change have also been pointed out as drivers of income inequalities within countries. Nevertheless, at the same time these impulses have helped reduce poverty in low-income countries, and not only in larger, faster developing ones, such as China and India, but also many others, including countries in Africa, as shown by the impact of smartphones.[2]

At the same time, inequality is also affected by technological revolutions. Technological changes combine with financial capital to create new techno-economic paradigms – the cluster of technologies, products, industries, infrastructure and institutions that characterize a technological revolution. In the countries at the centre of these new technological waves, the surge can be considered in two phases. First is the installation phase as technology is introduced into core industries – widening the gaps between workers in these industries and the rest. Second is the deployment phase which also tends to be uneven: not everyone gets immediate access to the benefits of progress such as a life-saving treatment, or access to clean water. The result is widening divisions which can lead to public discontent.

Figure 4
Technological revolutions and inequalities



Source: UNCTAD based on Perez (2002).

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At present, the world is reaching the end of the deployment phase of the “Age of ICT” and starting the installation phase of a new paradigm, involving frontier technologies and sometimes called Industry 4.0 (Figure 4). The deployment of ICT resulted in an enormous concentration of wealth in the ownership of the major digital platforms. How will Industry 4.0 affect inequalities between countries? Much will depend on whether countries are catching up, forging ahead, or falling behind – which in turn will depend on their national policies and on their involvement in international trade.

Responding to inequalities

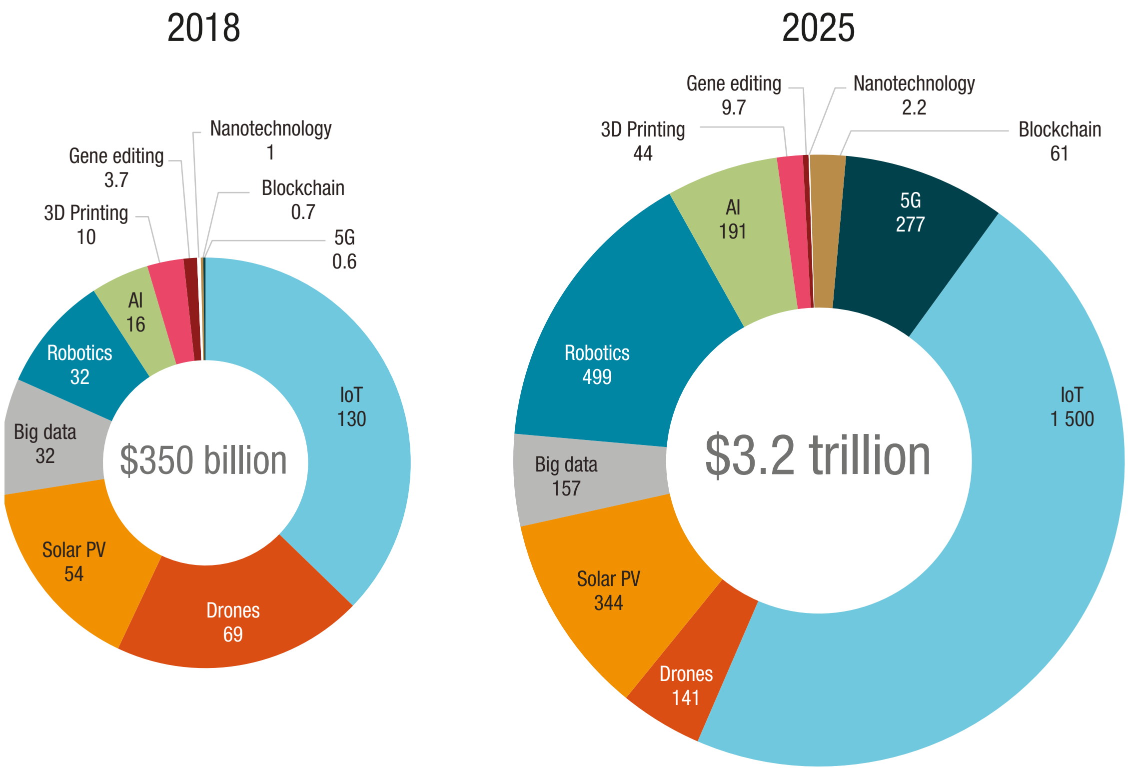
To some extent governments can mitigate inequalities within countries through progressive taxation on incomes or wealth, or on income from capital. They can also make services such as education freely available to all. Governments can also increase social transfers, such as unemployment benefits, which reduce the risk of people falling into poverty. And in the workplace these actions can be complemented by those of stronger trade unions which help to increase wages.

Reducing income inequality between countries will mean harnessing technology and trade for structural transformation. If developing countries are to create economies that offer their people better-paid jobs they will have to take advantage of the new technological paradigm. Developing countries, and whole continents such as Africa, cannot afford to miss this new wave of technological change.

2. FORGING AHEAD AT THE DIGITAL FRONTIERS

The “frontier technologies” are a group of new technologies that take advantage of digitalization and connectivity which enable them to combine to multiply their impacts. This report covers 11 such technologies: artificial intelligence (AI), the Internet of things (IoT), big data, blockchain, 5G, 3D printing, robotics, drones, gene editing, nanotechnology and solar photovoltaic (Solar PV).

Figure 5
Market size estimates of frontier technologies, $billions



Source: UNCTAD based on data estimates from Froese (2018), MarketsandMarkets (2018), Sawant and Kakade (2018), Business Wire (2019), Chaudhary et al. (2019), GlobeNewswire (2019), MarketsandMarkets (2019), MarketWatch (2019a), MarketWatch (2019b), Raza (2019), Tewari and Baul (2019), Wagner (2019), Mordor Intelligence (2020).

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These technologies can be used to boost productivity and improve livelihoods. AI, for example, combined with robotics can transform production and business processes. 3D printing allows faster and cheaper low-volume production and rapid, iterative prototyping of new products. As a group, these 11 technologies already represent a $350-billion market, and one that by 2025 could grow to over $3.2 trillion (figure 5).

Finance companies have used these technologies, for example, for making credit decisions, and for risk management, fraud prevention, trading, personalized banking and process automation. The manufacturing sector has used them for predictive maintenance, quality control and human-robot combined work.

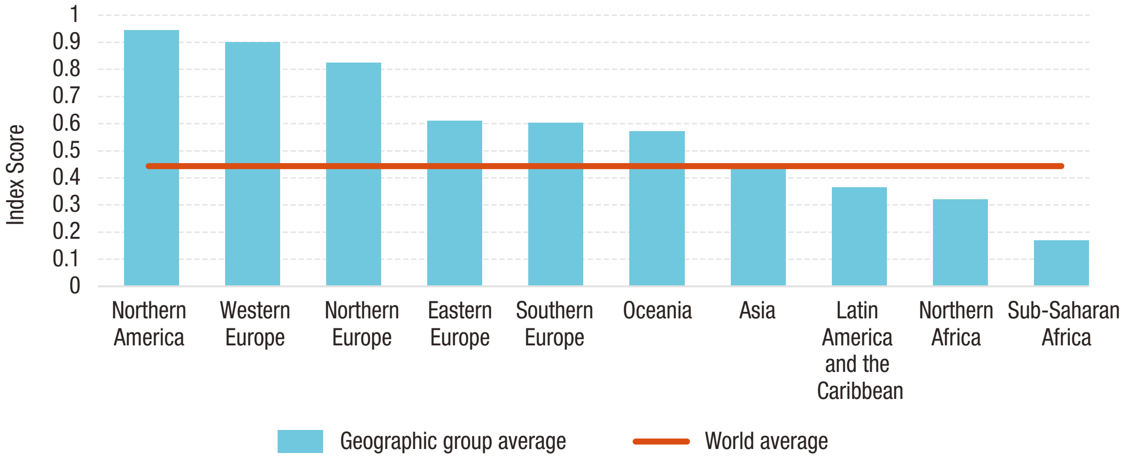
Many of the major providers of these technologies are from the United States which is home to major cloud computing platforms. China is also a major producer, notably of 5G, drones and solar PV. For each of the technologies, these two countries are also responsible for 30 to 70 per cent of patents and publications.

A country readiness index

Only a few countries currently create frontier technologies, but all countries need to prepare for them. To assess national capabilities to equitably use, adopt and adapt these technologies this report has developed a 'readiness index'. The index comprises five building blocks: ICT deployment, skills, R&D activity, industry activity and access to finance.

Based on this index, the countries best prepared are the United States, followed by Switzerland, the United Kingdom, Sweden, Singapore, the Netherlands and the Republic of Korea. The list also has high rankings for some transition and developing economies – such as China ranked at 25 and the Russian Federation at 27. Most of the least-ready countries are in sub-Saharan Africa, and in the developing countries generally.

Figure 6
Average index score by geographical group



Source: UNCTAD.

The countries ranked highest are largely the richest ones, but there are many outliers – countries that perform better than their per capita GDPs would suggest. The greatest overperformer is India, followed by the Philippines. On the R&D components of the index, China and India perform well, partly because these countries have abundant supplies of highly skilled but relatively inexpensive human resources. In addition, they have large local markets, which attract investment from multinational enterprises. Viet Nam and Jordan also do well, reflecting supportive government policy.

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3. HUMANS AND MACHINES AT WORK

Technological change affects inequalities through its impact on jobs, wages and profits. These inequalities could arise between occupations, firms and sectors as well as between wage earners and owners of capital. Another level in which inequality emerges is in the differences in the economic structures of countries. The contribution of each of these and other elements to income inequality depends on many factors, such as the country's level of development, its economic structure and its social and economic and labour policies, as well as the size of a specific sector or its firms. Therefore, at any given time, in a particular country, technological change could cause inequality to rise or fall.

Is this any different from what happened with previous waves of technology? In principle, no. The channels and mechanisms are similar. But each wave of technological change brings inequality in new shapes.

Automation taking jobs

Nowadays, a major concern is that AI and robotics will reduce employment. Indeed, since the onset of the industrial revolution workers have expected new technologies to destroy jobs. Generally this has not happened; new technologies have instead tended to create more jobs, and of different kinds. But for frontier technologies, the situation could be different because the changes are coming so quickly they could outpace the capacity of societies to respond.

Previously, many jobs were considered safe because it was difficult to teach computers how to perform them. Now, however, the computers can often teach themselves. Some estimates suggest that over the next 20 years, in Europe and the United States 30 to 50 per cent of jobs could be automated. Others see a more modest impact – from 8 to 14 per cent across occupations. Nevertheless, while some jobs will disappear, others will emerge – such as those requiring empathy, ethical judgements, inventiveness, managing unpredictable changes, or making decisions based on understanding tacit messages – all of which have to be carried out by humans.

Predictions on job losses are typically based on technological feasibility, but the more important factors are often economic. Even when it is technologically feasible, capital may not replace labour; much depends on relative prices. At the same time, the overall demand for labour could be increased by macroeconomic effects.

Another concern for developing countries is that multinational enterprises could take advantage of frontier technologies to keep production at home – or to reshore manufacturing that had previously been moved overseas. This process could slow the shift of traditional industries such as garments, footwear, and low-tech electronics from China to less-industrialized countries in Asia and Africa. The feasibility of reshoring does, however, depend on many other factors, including ownership, and the scale of production, and the country's position in the supply chain. It may also make more sense to keep production in developing countries that have growing populations and expanding middle classes which offer prospects of growing markets.

Job polarization

Job displacement can also be accompanied by job polarization, which refers to an expansion in high- and low-wage jobs combined with a contraction in middle-wage jobs. In developed countries there are, for example, now fewer clerks doing routine middle-wage jobs. Thus far, there has been less impact on the lowest-skill manual jobs, but that seems set to change with greater use of AI and nimbler robots.

Not all job polarization can be attributed to technological change, much will also have been an outcome of trade and international competition. In developed countries job polarization has been associated with a reduction in manufacturing and medium-skill jobs, and an increase in services and higher-skill jobs, while in middle-income countries there has been an increase in manufacturing and medium-skill jobs (Figure 7).

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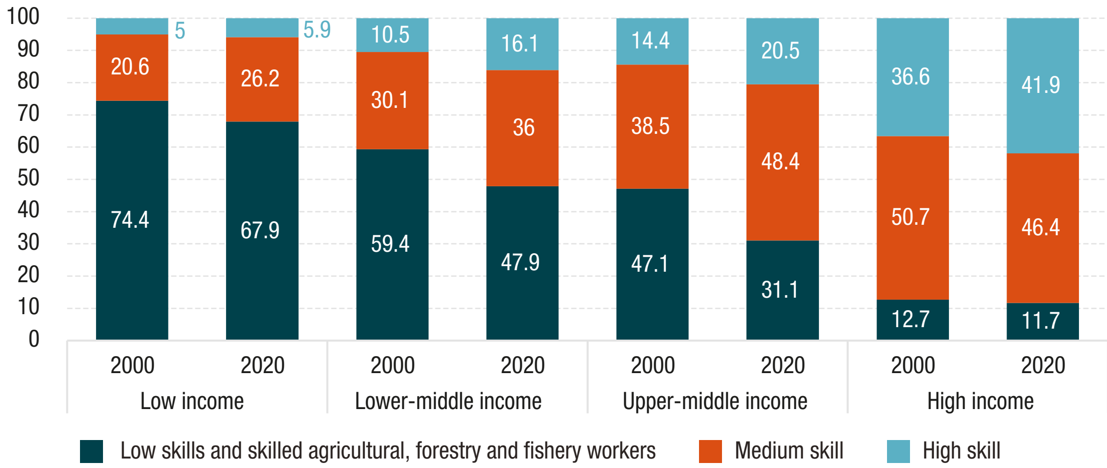
The wide differences in the economic structure of low, middle and high-income countries, as well as the unequal impact of international trade, are expected to also reflect in an uneven impact of frontier technologies on job polarization in different economies. In this regard, low- and middle-income countries are likely to be less affected.

Figure 7
Employment by skill level, country income grouping (percentage of total civil employment)



Source: UNCTAD based on data from ILOStat according to the ISCO-08.

The gig economy

Frontier technologies are being used to provide services via digital platforms that have spurred the creation of a 'gig economy'. Some of this work is locally based, but there is also "cloud work" that can be performed anywhere via the Internet. While the gig economy provides employment, this is typically on insecure terms, creating a precarious class of dependent contractors and on-demand workers. The consequences for inequality will depend on whether the gig workers are poor people who would otherwise be unemployed, or middle-class people looking for small additional incomes. Inequality will certainly rise if these jobs replace better-paid ones or replace full-time jobs with part-time ones, or if profits grow faster than salaries. The gig economy may also heighten gender inequality: women are less likely to be working on digital platforms, but they often do so for more hours than men and for significantly lower wages.[3]

If service occupations are tradable internationally, salaries may converge. This has happened in computer coding, for example, and in digital design as well as in medical diagnostics, paralegal assessments, and image recognition.

Market and profit concentration

These new digital platforms benefit from network effects, so that markets tend to concentrate, leaving a small number of large players. This reduces the incentive to cut prices – producing higher profits which can widen inequality between wage earners and the owners of capital. And for some IT skills these companies may be virtually the only employers – a "monopsony". With few companies there is also the temptation for tacit collusion as a result of data exchange through algorithms.

AI and global economic inequalities

The impact of AI on inequality between countries will depend to some extent on the type of input data. If AI primarily uses 'big data' generated by users, this would mainly benefit the United States and China, whose competing digital platforms gather massive amounts of such data. But if it primarily

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uses big data gathered by the Internet of things this would benefit other economies with strong manufacturing bases– such as the EU, Japan and the Republic of Korea.

A third AI scenario involves allowing computers to learn more like humans through repeated interactions of AI models. This would not particularly benefit the United States or China, but would still demand resources and capabilities more likely to be found in the developed countries, which would enable them to pull further ahead of the developing countries.

Widening technological gaps

There is also a fear that the widespread adoption of frontier technologies in developed countries will reduce the labour-cost competitiveness of today's less industrialized economies in Asia and Africa, increase the technological gaps between them and developed countries – make it more difficult to catch up, diversify their economies, and create jobs. In the past, countries like China, Mexico, Brazil, and a handful of Asian countries moved up the income ladder by transferring labour and capital from relatively lower-productivity agriculture to higher productivity manufacturing and services. The fear now is that frontier technologies and Industry 4.0 will upend these traditional development processes, making a difficult journey even harder.

Challenges for developing countries

Theories and models point to possible channels of impact, but the actual effect will depend on the sectors affected, on the capacities of countries, and on the policies and strategies adopted. However, experience shows that over time new technologies are likely permeate to various sectors of the economy and social activities. In these circumstances, developing countries should deliberately adapt and use automation to increase productivity, promote economic diversification and create jobs. Preparing people, firms and institutions for such changes can limit any negative effects on inequality.

In pursuing these policy objectives, developing countries will need to overcome a number of challenges.

- *Demographic changes* – Low-income- and lower-middle-income countries typically have expanding and younger populations – which will increase the supply of labour and depress wages, reducing the incentives for automation.
- *Lower technological and innovation capabilities* – Low-income countries have fewer skilled people and depend to a large extent on agriculture which tends to be slower to take advantage of new technologies.
- *Slow diversification* – Developing countries typically innovate by emulating industrialized countries, diversifying their economies, and absorbing and adapting new technologies for local use, but this process is slowest in the poorest countries.
- *Weak financing mechanisms* – Most developing countries have increased their R&D expenditures, but these are still relatively low. The African Union, for example, has established a target of one per cent of GDP, but on average sub-Saharan African countries are still at 0.38 per cent.[4] There is very little private funding of industrial technologies for productive applications.
- *Intellectual property rights and technology transfer* – Stringent intellectual property protection will restrict the use of frontier technologies that could be valuable in SDGs related areas such as agriculture, health and energy.

Accelerating towards industry 4.0

Many national and local governments are working to stimulate the growth of new industries and services that produce jobs and wealth and promote human development. To be fully effective, they need to set strategic directions through national plans for research and innovation which can take on emerging social challenges such as ageing and regional disparities.

National innovation policies also need to align with industrial policies. Keeping national or regional industry competitive is a central goal in most strategic plans for AI and Industry 4.0 technologies. These plans can take advantage of UNCTAD's *Framework for Science, Technology, and Innovation Policy (STIP) Reviews* which can lead to specific policies for harnessing frontier technologies for smarter, more sustainable cities, food security and smart agriculture, and employment generation in smarter factories.

In many cases this will require access to patented technologies. One option is compulsory licensing, but there can also be more collaborative agreements, along with patent pooling, clearing houses, and open-source licensing. At the same time, governments can finance R&D while requiring that the benefits of this research serve the public good.

Some of the finance for innovations can come from official sources, but alternative models for funding include impact investment, venture capital, crowdfunding, and Innovation and technology funds. There have been some successes: in 2018, annual equity funding for tech startups in Africa doubled to more than $1 billion.

At the same time, policymakers need to anticipate the impacts on the workforce. To take full advantage of these technologies, workers will need competencies in science, technology, engineering and mathematics (STEM) – as well as in design, management and entrepreneurship. Workers who cannot be trained or retrained, and lose their jobs, should be able to rely on stronger mechanisms of social protection and workfare as well as on different forms of income redistribution such as negative income tax, and universal basic income. There is also a renewed importance of labour unions to defend workers' rights and the legitimate concerns about their jobs in the digital economy and increasing automation of tasks.

Finance for such measures could come from "robot tax" which would gather income from the technologies that replace workers. Or there could be an automation tax, combined with removing corporate tax deductions for investment. On the other hand, rather than taxing individuals or technologies, it might be better to tax the resulting wealth.

4. INNOVATION WITH EQUITY

Frontier technologies have huge potential for improving people's lives and protecting the planet. During the COVID-19 pandemic, for example, AI and big data have been used for screening patients, monitoring the outbreaks, tracking and tracing cases of the disease, predicting its evolution and assessing infection risks. Other examples have ranged from the use of IoT to monitor the quality of groundwater in Bangladesh, to the use of drones for delivering medical supplies to remote communities in Rwanda and Ghana.

But technology is rarely a solution on its own. Problems such as poverty, hunger, climate change or inequalities in health or education are inevitably complex and multidimensional. Technology, frontier or otherwise, may support initiatives of all kinds, social, political, or environmental, but all technology needs to be used carefully if it is to help rather than hinder, or produce unintended side effects.

Technologies are likely to have an effect on disparities, but inequalities can also shape technologies – so that they reflect, reproduce and perhaps amplify systemic bias and discrimination. Currently most technologies are created by firms in the global North and predominantly by men. They tend to focus on the demands of the rich, crowding out innovations that might benefit the poor. Technological change is also shaped by gender inequalities, partly because men have been more likely than women to study STEM subjects.

Technologies affecting inequalities through access and design

People are affected as consumers of goods and services that apply frontier technologies. One of the most critical aspects is access – which can be considered to comprise a combination of "five A's": availability, affordability, awareness, accessibility, and ability for effective use. Access to technology

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can also be restricted by social norms – for women, ethnic minorities and other disadvantaged groups, even within the same household.

Another important aspect is design. Developers should also be mindful that the ways that they design, and that people use, technologies can have unintended consequences.

Risks of bias and discrimination

Many concerns are related to the biased design and unintended consequences of AI. Biases within AI systems can arise in a number of ways, either because they employ biased algorithms, or they use biased data for training. For example, AI can perpetuate stereotypes and reduce the benefit of products for women.

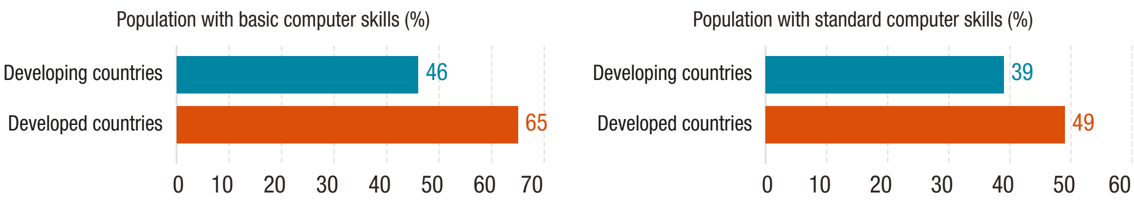
The benefits are also likely to be unevenly distributed in the case of gene editing: most of the research is in richer countries with the prospect of monopoly ownership of technologies, which could limit their contribution to achieving the SDGs, particularly those related to food production and health. Gene editing also raises ethical questions of what constitutes an ideal human being. This could result in an underclass of people who cannot afford genetic treatment.

Challenges for developing countries

Developing countries face three main challenges in promoting equal access to the benefits of frontier technologies:

- *Income poverty* – Many people in developing countries cannot afford new goods or services, particularly those in rural areas. In this case the barriers are not technological but economic and social.
- *Digital divide* – Many frontier technologies rely on steady, high-speed fixed Internet connections, but almost half of the world's population remains offline. Many developing countries lack adequate digital infrastructure, and for most of their people Internet costs are prohibitive.
- *Shortage of skills* – In developing countries, the basic and standard skills are on average 10 to 20 percentage points lower than in developed countries (Figure 8). Many frontier technologies require at least literacy and numeracy skills. Other technologies require digital skills, including the ability to understand digital media, to find information, and to use these tools to communicate with others.

Figure 8
Gaps in digital skills



Source: UNCTAD based on ITU (2018, 2019).

Directed to sustainable development

To overcome these challenges, Governments and the international community need to guide new and emerging technologies so that they support sustainable development and leave no one behind. From the outset, it will be important to establish ethical frameworks, particularly for the deployment of AI. Many voluntary initiatives are already aiming to ensure that the processes and outcomes are fair, transparent, accountable, and inclusive. Similarly, for human germline gene editing there needs to be a broad consensus on ethical and societal issues.

Governments should also try to foster supportive innovation ecosystems, based on assessments that analyse different techno-system paths and their impacts on inclusive and sustainable development. An example of international cooperation which assists with that task is UNCTAD's programme on STI Policy Reviews.

The chosen technologies then need to be deployed at scale, with plans to pass the baton from scientists and engineers to entrepreneurs and others, and to boost household incomes. The technologies can also be embedded in services provided by the public sector, with special attention for underserved areas that are not commercially viable for private companies. Networks of activists, academics, and practitioners can experiment with alternative possibilities – based on local knowledge and driven by environmental and social needs.

5. PREPARING FOR THE FUTURE

Technological progress is essential for sustainable development, but can also perpetuate inequalities or create new ones, either by limiting access to more privileged groups and affluent countries, or through built-in biases or unintended consequences. The task for governments is thus to maximise the potential benefits, while mitigating harmful outcomes, and ensuring universal access. Countries at all stages of development should promote the use, adoption and adaptation of frontier technologies, preparing people and firms for what lies ahead. An important requirement is effective national governance: the state needs to create the vision, the mission and the plan for creating and shaping the market for inclusive and sustainable innovations.

Governments will also need to invest in human and physical resources. To help them do so, developing countries should be able to rely on international cooperation, communities of nations working together to build an international institutional framework that embraces countries at all stages of technological development.

These official policies and programmes will need to be supported by vigorous social activism, with people and organizations cooperating to identify mismatches between technological innovation and societal responses. Keeping the SDGs as central guiding principles will require constant vigilance from civil society organizations.

For reducing inequalities, governments can draw from a broad range of instruments including regulatory measures and economic and fiscal instruments, as well as smarter policies on trade, investment, industry, education and innovation. They can also ensure that vulnerable and low-income groups have access to valuable new goods and services some of which can be subsidized or provided free.

Twin technology targets

To catch up and forge ahead, developing countries will need to adopt frontier technologies while continuing to diversify their production bases by mastering existing technologies. They need to keep to both targets in sight. This will mean strengthening innovation systems, while aligning STI and industrial policies, building basic digital skills, and closing gaps in ICT infrastructure.

- *Strengthen national innovation systems* – Governments should engage a wide range of actors who can help build synergies between STI and other economic policies – industrial, trade, fiscal, and monetary, as well as educational policies.
- *Align STI and industrial policy* – Together these should attract firms into the core sectors of frontier technology development and deployment. This would enable traditional production sectors to benefit from multiple channels of diffusion, covering foreign direct investment, trade, and intellectual property rights, patents and the exchange of knowledge and know-how.
- *Develop digital skills* – Education and training programmes should be inclusive and specifically involve women.
- *Focus on the furthest behind* – Countrywide access to electricity and to ICT should aim to bridge gender and generational gaps. Through inclusive National Digital Agendas countries can focus on the furthest behind, leveraging ICT infrastructure and improved Internet access through fixed or mobile broadband.

Mitigating risks

There is always the risk that rapid technological change will cause harm or perpetuate or accentuate inequalities. This should prompt public responses to:

- *Strengthen social protection* – During labour market disruptions workers should be able to rely on robust systems of social protection. Options include universal basic income schemes which might be financed by taxing capital, robots or other technologies.
- *Ease workforce transitions* – In addition to encouraging training and re-training through the public and the private sectors, government agencies may also support workers with personal counselling and improved job matching, and placement services. The youngest workers can benefit from apprenticeship programmes.
- *Anticipate the future* –This will require 'technological foresight and assessments' – eliciting knowledge from a variety of actors about the industrial growth areas that match a country's strengths to commercial opportunities.

Priorities for international cooperation

Developing countries should also be able to rely on technical and financial support through international cooperation and official development assistance (ODA). In particular this will be needed to:

- *Build stronger national capacities in STI* – This will mean increasing the relatively small amounts of ODA directed to STI in the least developed and low-income developing countries.
- *Smooth technology transfer* – The international community can facilitate technology transfer for locally relevant products and services. This may involve liberalizing access to trade and to technologies covered by intellectual property rights.
- *Increase women's participation* – If women are to play their full part in frontier technologies, governments and international organizations will need to encourage girls and women to study science, technology, engineering and mathematics (STEM) subjects.
- *Improve foresight and technological assessment* – The international community can support strategic 'foresight and technological assessment' initiatives to better understand the socio-economic and environmental implications of new and innovative technologies.
- *Promote inclusive debate* – Developing countries, especially the least developed countries, need to be part of international debates on how new technologies affect citizens' rights, privacy, data ownership and online security – and especially on how they can promote the SDGs. Developing country concerns need to be reflected in normative frameworks and regulatory regimes – balancing individual and collective rights, while encouraging private sector innovation.

Catching the wave

Developing countries, particularly low-income countries, cannot afford to miss this new wave of technological change. Each country will need STI policies appropriate to its stage of development. For some this will mean promoting frontier technologies, while renewing efforts to take full advantage of existing technologies to diversify their economies and upgrade traditional sectors. Others can engage more deeply with the development and adaptation of frontier technologies. But all developing countries need to prepare people and firms for a period of rapid change. Success in the twenty-first century will require a balanced approach – building a robust industrial base and promoting frontier technologies that can help deliver the 2030 Agenda and its global vision of people-centred, inclusive, and sustainable societies.

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2 Jaumotte et al., 2013
3 Barzilay and Ben-David, 2016
4 UNESCO, 2019

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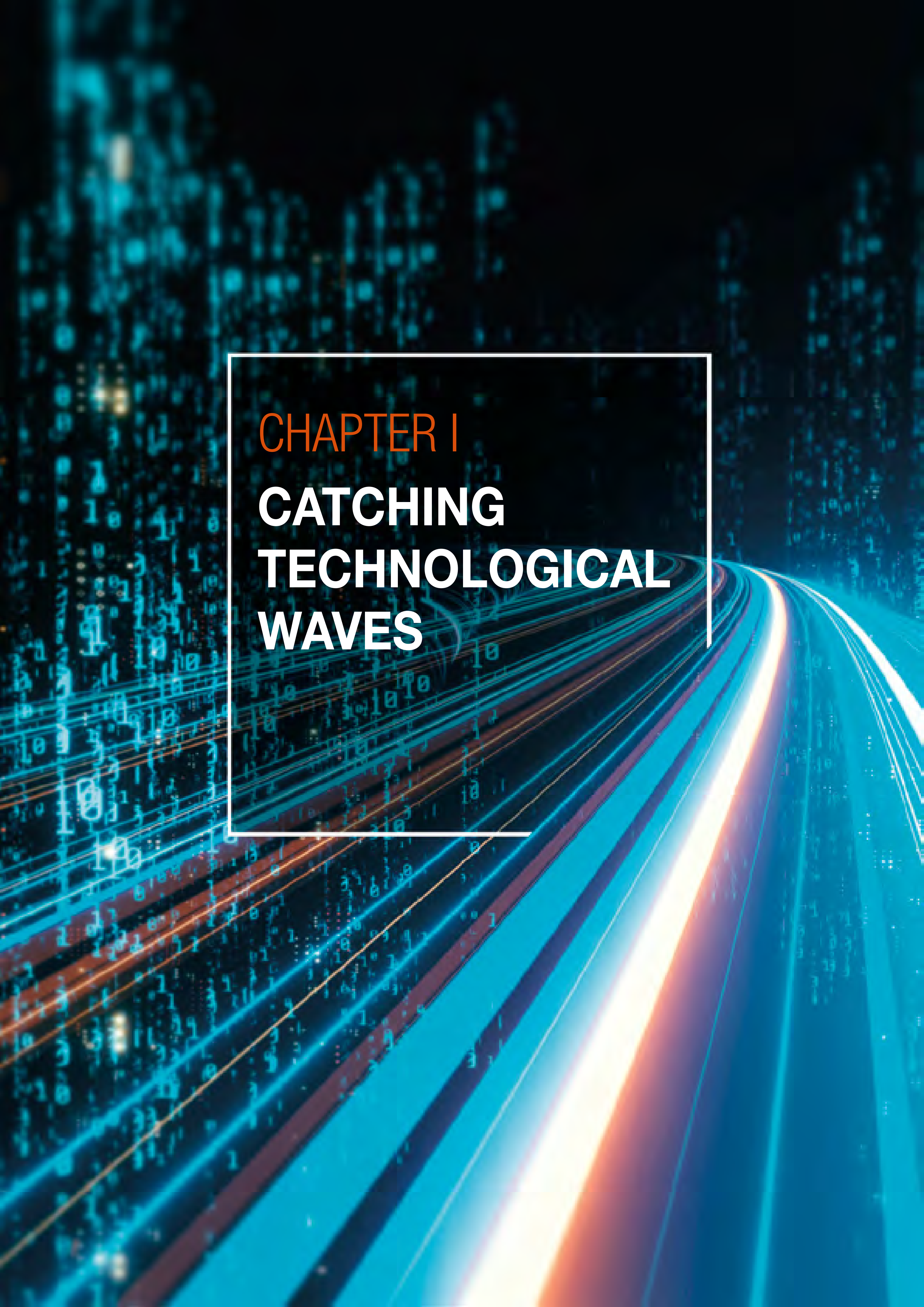
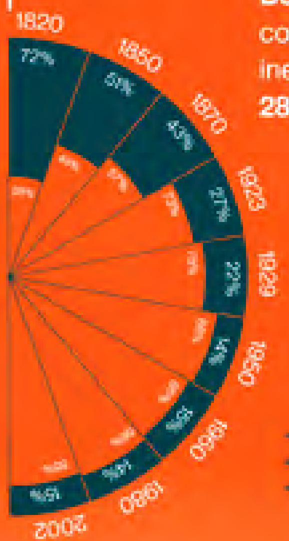


CHAPTER I

CATCHING TECHNOLOGICAL WAVES

Frontier technologies have already brought enormous benefits, but rapid advances can have serious downsides if they outpace the ability of societies to adapt. The implications could be serious for developing countries – if poor communities and countries are either overwhelmed or simply left behind.

The great divides between countries that we see today started with the onset of the first industrial revolution. Since then, every spurt of progress was associated with sharper inequality between countries.



Between 1820 and 2002, the contribution of between-country inequality to global inequality rose from **28% to 85%.**

The outcomes for one generation affect the opportunities for the next – resulting in intergenerational transmission of inequalities

Inequality has many dimensions and could be impacted by many factors. One of them is the impact of technological revolutions.
How the new technological wave affects inequalities in developing countries – and inequalities between countries – will depend on national policies.

Governments can shape the policy environment and build domestic productive and innovation capacities so as to minimize the risks and maximize the benefits – achieving innovation with equity.

Human development over the past two decades has been accompanied by rapid changes in technology and an increasing proliferation of digitized devices and services. In many respects these have been beneficial. Innovation has driven economic development – and the pace of change seems likely to accelerate as a result of digitalization and advances in "frontier technologies" such as artificial intelligence (AI), robotics, biotechnology, and nanotechnology, all of which could help countries achieve the Sustainable Development Goals (SDGs).

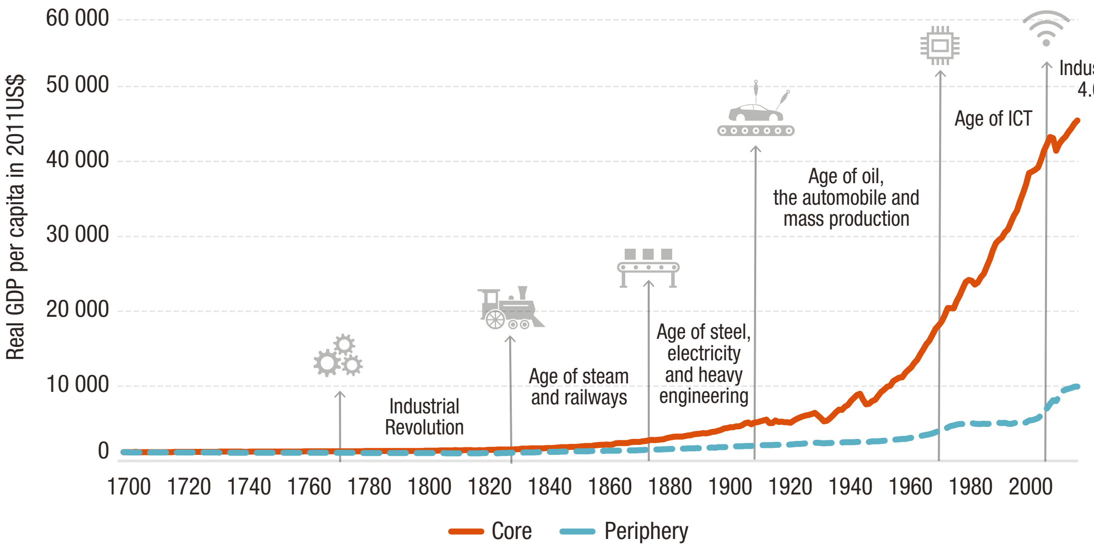
New technologies have also proved critical in combating COVID-19. Biotechnology, for example, has been used to identify the virus and test for infection. And through broadband technologies and social media people have been able to connect while in physical isolation – facilitating business continuity and children's education, as well as good mental health.[1]

But new technologies can also have serious downsides. Rapid technological change threatens to outpace the ability of societies to adapt. There are fears that jobs are disappearing as more economic activity is automated and that social media are exacerbating divisions, anxiety, and doubt. Overall, there are concerns that frontier technologies will further widen inequalities, or create new ones.[2]

Most of the discussion has focused on developed countries, but these technologies also affect developing countries. Here too there are concerns – about widening inequalities within and between countries. Are these justified? In some measure, yes. The great divides between countries that we see today started after the first industrial revolution, and we live at the beginning of a new technological revolution.[3] Before the industrial revolution, most people were equally poor and the gaps in per capita income between countries were much smaller.[4] But with the industrial revolution and subsequent waves of technological change, a group of countries pulled ahead, with rapid and sustained economic growth that enabled more of their people to escape poverty (Figure I1). Western Europe and its offshoots – Australia, Canada, New Zealand and the United States – along with Japan formed the core of the global economy. Most other countries remained on the periphery with fickle or minimal levels of growth and correspondingly low incomes.[5]

Figure I 1

The great divide, and waves of technological change



Source: UNCTAD, based on data from Maddison Project Database, version 2018, Bolt et al. (2018), Perez (2002), and Schwab (2013).

Notes: "Core" corresponds to Western Europe and its offshoots (i.e. Australia, Canada, New Zealand, the United States) as well as Japan. "Periphery" corresponds to the world, excluding the "core" countries.

Every spurt of progress was associated with sharper inequality between countries – with widening disparities in access to products, social services and public goods – from education to health, from ICT infrastructure to electrification. Nevertheless a few countries, notably in East Asia, were able to catch up through technological learning, imitation and innovation.

How will the latest frontier technologies affect inequalities for developing countries? How can governments minimize risks and maximize opportunities? And how can international cooperation help? This report seeks to answer these questions. It argues that developing countries can catch these new waves of technological change and ride them to diversify their economies, promote structural transformation and achieve sustainable development. This will require different strategies at different stages of development. More technologically advanced countries can guide these technologies towards positive goals, while other countries can selectively adopt and adapt those that best meet their needs. But all countries should be using these technological advances to help tackle poverty, reduce inequality and protect the planet.

Governments can shape the policy environment and build domestic productive and innovation capacities so as to minimize the risks and maximize the benefits – achieving innovation with equity. This will require a balanced approach, protecting people while ensuring that these new technologies are used to build robust and sustainable productive capacities. At the same time, civil society organizations should be pressing for more equal and sustainable futures. All this activity can be supported by stronger international cooperation. The report was prepared in the midst of the COVID-19 pandemic whose long-term implications are not yet clear. Nevertheless, the deep structural factors it addresses will apply both in normal times and in times of crisis.

Chapter I – *Catching technological waves* – Summarizes the current state of global inequalities – indicating both their extent and their drivers.

Chapter II – *Forging ahead at the digital frontiers* – Looks at the rapid proliferation of frontier technologies, and introduces a readiness index which shows which countries are best prepared to use, adopt and adapt these technologies.

Chapter III – *Humans and machines at work* – Shows how frontier technologies could transform economies and workplaces, affecting jobs, wages and profits. It also indicates national strategies for taking advantage of these technologies, promoting their use, adoption and adaptation to diversify and transform the structure of their economies and generate higher and sustainable incomes.

Chapter IV – *Innovation with equity* – Assesses the impact of frontier technologies on users. In particular, it looks at how the poor may be disadvantaged, either by lack of access, biased design or unintended consequences. Governments will need to improve access to digital infrastructure, develop the necessary skills and scale up innovations that target the poor.

Chapter V – *Preparing for the future* – Argues that countries at all stages of development should promote the use, adoption or adaption of frontier technologies. The impetus needs to come not just from national governments and civil society but also from the international community. Together they can foster a global ecosystem that encourages innovation while protecting the vulnerable and ensuring access for all.

The conceptual framework used in this report to link technologies and inequalities is presented in Annex A. Conceptual framework.

A. PROSPERITY AMIDST POVERTY

During recent decades of digitization, the world has seen growing prosperity. People on average are living longer and healthier lives, getting more education and better access to clean water, sanitation and electricity. Incomes too have been rising. Rapid economic growth in emerging economies has fuelled the rise of a global middle class.

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At the same time there is persistent poverty; these advances have been accompanied by rising inequality.[6] Wealth is highly concentrated: the richest 1 per cent of the global population own more than the poorest 90 per cent.[7] There are also wide disparities in income earning opportunities as well as in standards of education and health – which vary according to gender, urban or rural location, and country of birth. Although inequality between countries has fallen recently, it remains high, and most countries have seen a rise in income inequality.[8] There are also urgent issues of racial justice: in many cities across the globe people have taken part in widespread protests against systemic racism and the corrosive divisions that it perpetuates.[9]

These disparities have come into sharp relief as a result of the COVID-19 pandemic. At greatest risk are the poorest. People living in crowded slums with poor sanitation, or in refugee camps, find it hard or impossible to practice social distancing – and those with pre-existing health conditions are more vulnerable, along with the elderly. Millions of the working poor employed in small and middle-sized enterprises or in the informal sector have no savings with which to weather the crisis. The pandemic has also hit children's education and nutrition. Some can log into remote learning systems, but many lack basic Internet connections or devices. And while better-off children can get good meals at home, the poorer children may miss out on nutritious school lunches.

> Every wave of progress was associated with sharper inequality between countries from education to health, from ICT infrastructure to electrification.

The lower-income and least developed countries find it more difficult to support people and businesses through the crisis. They have fewer resources, lower technological capabilities and less productive industries and agricultural sectors. They also lack the foreign exchange needed to import essential goods such as personal protective equipment.[10]

High levels of inequality not only undermine human development and reduce resilience in the current crisis, they also heighten vulnerability to climate change, constrain economic growth and human development, and can destabilize societies.

B. MULTIFACETED INEQUALITIES

Inequality as covered in this report is a multifaceted concept. In the context of development, it relates to differences in outcomes and opportunities across individuals, groups or countries. These differences can be connected to any dimension of development – social, economic or environmental – and they have been receiving increasing international attention. For example, a core principle of the 2030 Agenda for Sustainable Development is to reduce inequalities "leaving no one behind."

These inequalities may have arisen from circumstances beyond the control of the individual – ethnicity, for example, country of birth, family structure or gender. They can also arise from factors that are intrinsic to the individual such as talent and effort. However, a more significant contribution to the disparities is inequalities in opportunities – in access to education, for example, or health services or to the goods and services that people need to be able to make best use of their talents and efforts.[11] Inequality of outcomes and opportunities are closely intertwined. The outcome for one generation affects the opportunities for the next – resulting in intergenerational transmission of inequalities.

Inequalities can be measured in terms of outcome indicators such as incomes, health standards or educational attainment – looking at gaps between countries and between individuals and groups, based on gender, age group, ethnicity or religion.[12] Figure I2 illustrates the inequalities between country groups across several development dimensions. Despite considerable progress, there are still wide inter-country disparities. In upper-middle-income and high-income countries, the average share of the population living in extreme poverty is only 2 per cent, but in lower-middle-income countries it is 14 per cent and in low-income countries 45 per cent. Similar disparities are seen in child mortality rates and in the prevalence of underweight children as well as in education, particularly at higher levels: in 2018, in low-income countries only 41 per cent of the population in the relevant age group were enrolled in secondary education – compared with 90 per cent in upper-middle-income and high-income countries.

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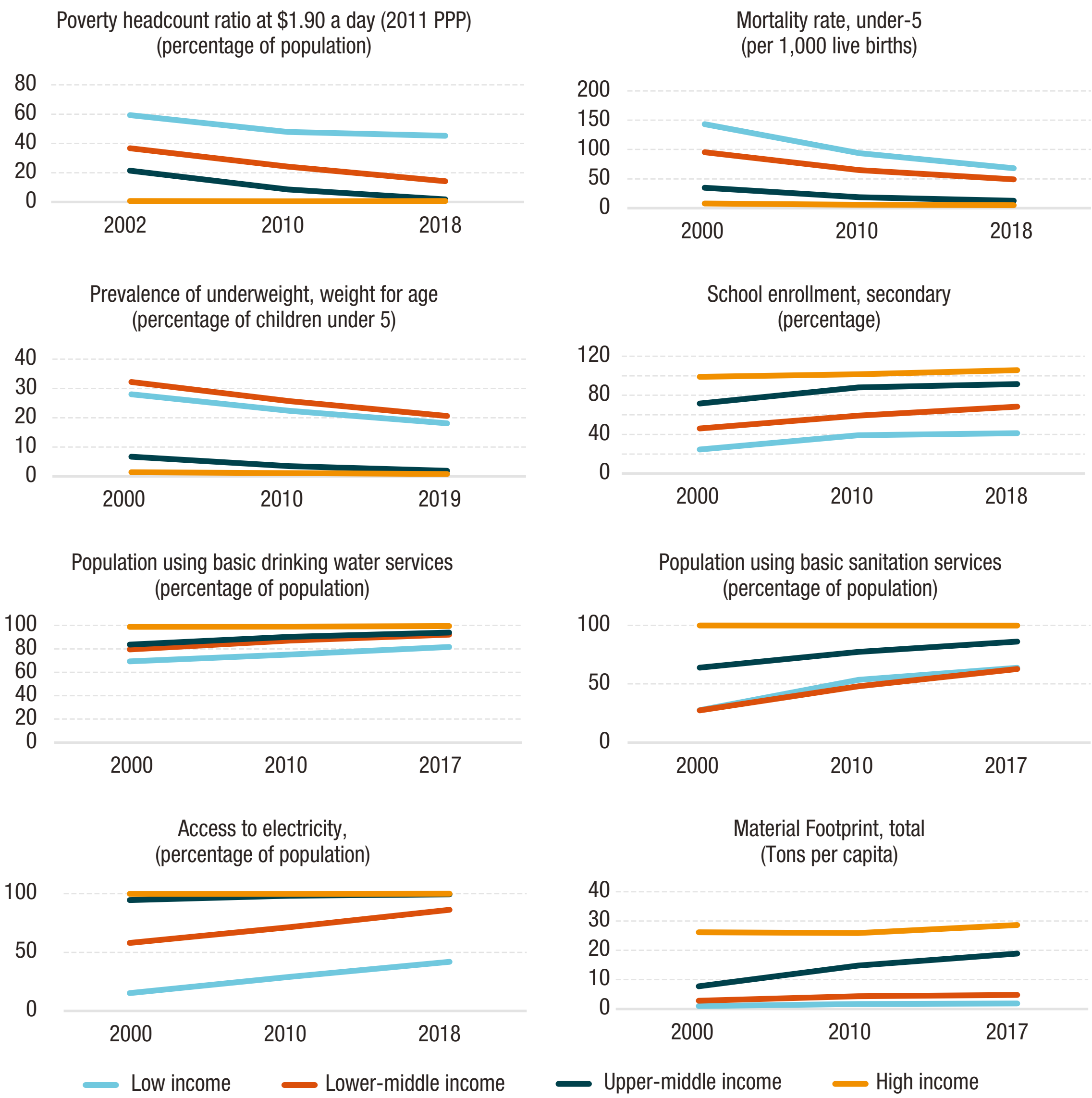
Progress has been faster for access to essential services such as clean water and electricity, but slower when it comes to access to basic sanitation and there are still wide disparities between low-income and other country groups. In low- and lower-middle-income countries, only 63 per cent of the population have access to basic sanitation, compared with 86 per cent in upper-middle-income countries, and universal access in high-income countries.

The low- and lower-middle-income countries also tend to have wider internal inequalities. This is illustrated in Figure I3 for selected SDG indicators. In 2018 in low-income countries, only 33 per cent of the rural population had access to electricity, compared with 70 per cent in urban areas. This gap was much narrower in lower-middle-income countries – rural 81 per cent and urban 96 per cent – and basically non-existent in upper-middle-income and high-income countries. Low-income countries also had more pronounced gender disparities in literacy rates, in the extent of vulnerable employment and in mortality-rates.

Figure I 2

Gaps between country groups, selected SDG indicators



Source: UNCTAD based on data from the World Bank and ESCAP.
Note: Some countries have moved between country groups during the period considered in the various charts.

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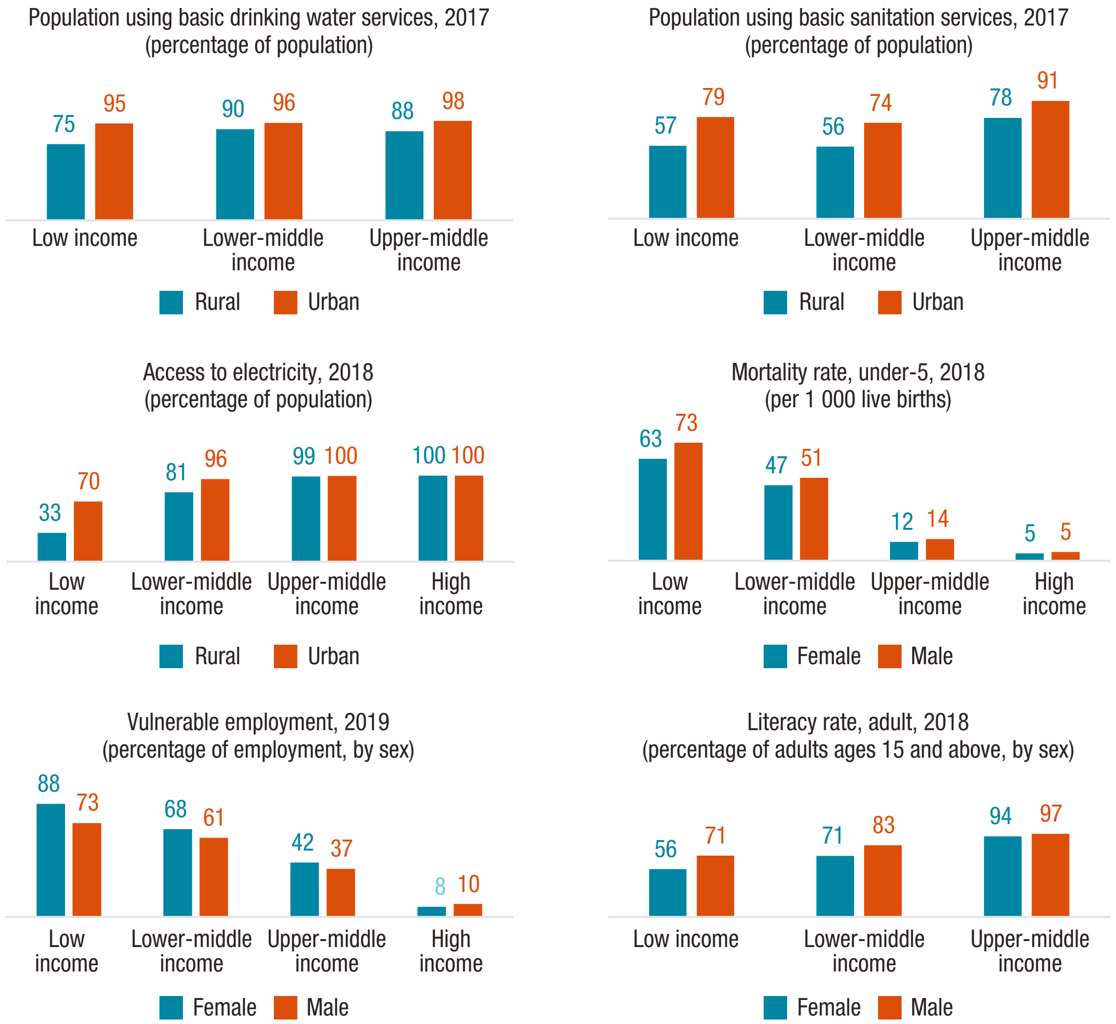
Figure I 3
Inequality within countries, selected SDG indicators



Source: UNCTAD based on data from World Bank and ESCAP.

Existing inequalities also have severe effects on the capacity of people to weather shocks (Box I1).

Box I 1
Inequalities and resilience in times of COVID-19

COVID-19 has accelerated some global trends, such as digitalization, while decelerating others, including greenhouse gas emissions. The pandemic has led to abrupt changes in work practices, and in educational methods and health arrangements. In so doing it has further widened many inequalities.

Even within the most developed countries the pandemic has increased poverty and reduced access to food.[13] During lockdowns, much of the burden has fallen on women, who are also 70 per cent of the front-line workers. At the same time, there has been an increase in domestic violence and child abuse.

As schools closed, much education moved online. Some students started working online early on in the crisis, while others had no access to online platforms – particularly students in less advantaged areas within developed nations.

Work has also been moving online. During the lockdown in the EU more than one-third of the labour force was teleworking. But not everyone could do so; lower skilled workers employed in "high-touch" jobs such as food retail or transport had to show up for work, exposing them to COVID-19. These jobs were usually less well paid,

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less secure and offered less access to healthcare. In most cases, the poorer the country, the harder it is to telework.

During the pandemic, there have been some benefits from frontier technologies. For testing, for example, machines are not only able to analyse lab results and work 20+ hours and perform over 600 tests a day, but they also help professionals with social distancing.

How can the international community best respond, and transform the COVID-19 crisis into an opportunity? The key is building resilience. This is understood at the country level as the capacity to recover and rebuild.[14] This notion should now be further expanded to transform societies in a sustainable, fair, and democratic manner.[15] In other words, resilience should enable a nation to bounce forward, to come out stronger and better prepared for future shocks.

There have been some attempts to measure national resilience to external shocks. For example, in a forthcoming study the European Union assessed countries on their ability to bounce back, on financial coping and life attitudes.[16] It found that the people most resilient were those in Denmark, Finland, Sweden, Luxemburg and the Netherlands.

Resilience originates in people, in their internal strengths, and in their safety nets, jobs, savings and well-being. It also relies on well-functioning financial systems, digital infrastructure, social protection, and health systems as well as on trust in governments. Governments act as the ultimate absorbers of risks and will need to build resilience to prepare for future shocks.

Source: UNCTAD.

C. WIDE INCOME GAPS

Many of the equalities illustrated also correlate with levels of income.[17] Indeed income inequality can serve as a proxy for other forms of disparity, though it should be noted that even countries with the same levels of income can have very different development outcomes – with much depending on public policies.[18]

Income inequality is usually measured using the Gini coefficient, which runs from zero to 1, where zero represents complete equality, and 1 which means one person owns everything. In more egalitarian societies such as those in Scandinavia, the Gini is 0.2 to 0.3. More unequal countries such as the United States have Ginis around 0.4. In some Latin American and Asian countries, the level is around 0.5. But the highest levels are in Namibia (0.59), South Africa (0.63) and Zambia (0.57).[19]

Inequalities within countries erode their economies, social fabrics, and natural environments.[20]

- *Economy* – Highly unequal countries tend to have lower growth rates. People at the bottom of the distribution scale are unable to acquire the skills and assets required to contribute to the economy, thus reducing growth.[21] [22]
- *Opportunities* – Higher inequality tends to be transmitted from one generation to the next.
- *Poverty* – Inequality also hinders poverty reduction. High initial levels of inequality reduce the effect of economic growth on poverty reduction, while increasing inequality increases poverty for any rate of growth.[23]
- *Political control* – More unequal societies also run higher risks of political capture by the rich. They may then reduce their taxes and their support for public goods and services, including education and health, that are mainly directed to the poorer segments of the society, thus reinforcing and perpetuating inequalities.
- *Polarization* – Many consider inequality to be an important driver of the recent political polarization in many developed and developing countries.[24] It can reduce trust in democratic institutions.[25]
- *Environment* – There can also be environmental impacts, since unequal societies tend to show lower support for environmental protection. At the same time, disadvantaged groups are more affected by environmental threats, including the effects of climate change.

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The term global inequality refers to inequality among all world citizens including the richest people in rich countries and the poorest people in poor countries, so is understandably higher at around 0.7.[26] Nevertheless, for the first time since the onset of the industrial revolution, over the past 10 to 15 years, global inequality has decreased.

This is because some large developing countries have grown faster and have been catching up with the developed countries. Most are in Asia, notably China, along with India, Indonesia and Viet Nam. To some extent these countries have followed the same trajectory of industrialization and structural transformation as the richer countries. But they have had to do so in different circumstances in a changing world economy that is more reliant on trade, investment, and technological learning. To be able to compete in the 2000s they had to find their own path. Their advances also had benefits for other developing countries in Africa and Latin America by increasing the demand for primary resources. As a result, the middle of the global income distribution has become more populated, while more people in relatively poorer countries have become less poor.[27]

However, in Africa, this trend to lower inequality is being countered by demographic change. Previously, most African countries were among the poorest, but they had smaller populations so made a lower contribution to global inequality. But populations in African countries are now growing faster than those in other regions. The number of people in extreme poverty in sub-Saharan Africa has increased in recent years and is now higher than the number of poor in all other regions combined.[28] If countries of the region are unable to catch up in terms of income the result will be greater global inequality – with a widening gap between African countries and those in North America, Europe and Asia.

OVER THE PAST 40 YEARS

INCOME INEQUALITY HAS INCREASED
IN MANY COUNTRIES

In the longer-term the reduction in global inequality could also be derailed by climate change. Countries that rely on a few primary products may experience new weather patterns that reduce agricultural production and food security. Poorer countries and low-income groups in middle-income countries are also vulnerable to weather disasters – whose frequency and intensity could be increased by climate change. They are also exposed to health crises such as the COVID-19 pandemic.

Achievements in global equality are also threatened by rising disparities within countries. Over the past 40 years income inequality has increased, not only in the United States and Europe, but also in developing countries such as China and India. In China, for example, between 1980 and 2015 the top 1 per cent increased their share of pre-tax national income from 6.5 to 14 per cent while over the same period, the bottom 50 per cent experienced a fall in its share from 27 to 15 per cent (Figure I4). In India, the increase in disparity was greater; the top 1 per cent increased its share from 7 to 21 per cent, while the bottom 50 per cent reduced its share from 23 to 15 per cent.

Thus, while disparities between countries have been falling, those within countries are widening. What is the net effect for global inequality? To answer that question, we must consider the contribution of inequality between and within countries to global inequality. Estimates suggest that the contribution of between-country inequality is enormous; between 1820 and 2002 it has rose from 28 to 85 per cent (Figure I5). In other words, in 1820, global income inequality was driven by class divides within countries, while now it is driven by the lottery of country birthplace.

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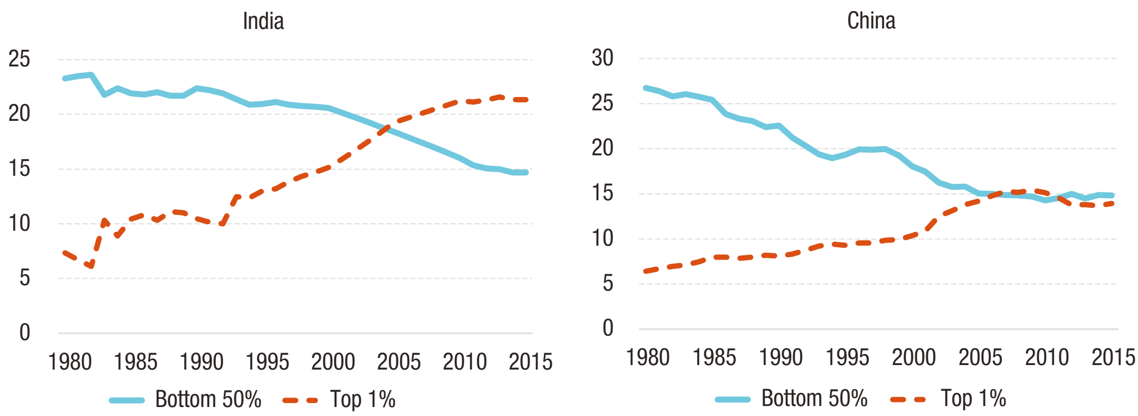
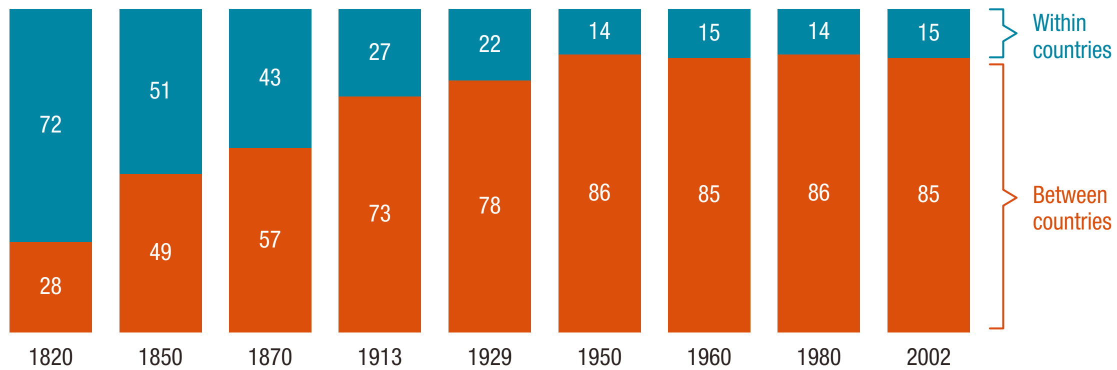
Figure I 4
Increasing income inequality, China and India (share of pre-tax national income, percentage)



Source: UNCTAD based on data from the World Inequality Lab.

This has given rise to the concept of the `citizen premium' for being born in a rich country. Estimates suggest that just by being born in the United States instead of Congo, an individual will multiply his or her income 93 times. Those born in poor countries thus suffer a 'citizen penalty'. Moreover, the gap between developed and developing countries is even larger for the very poor.[29]

Figure I 5
Contribution of inequality between and within countries to global inequality (percentage)



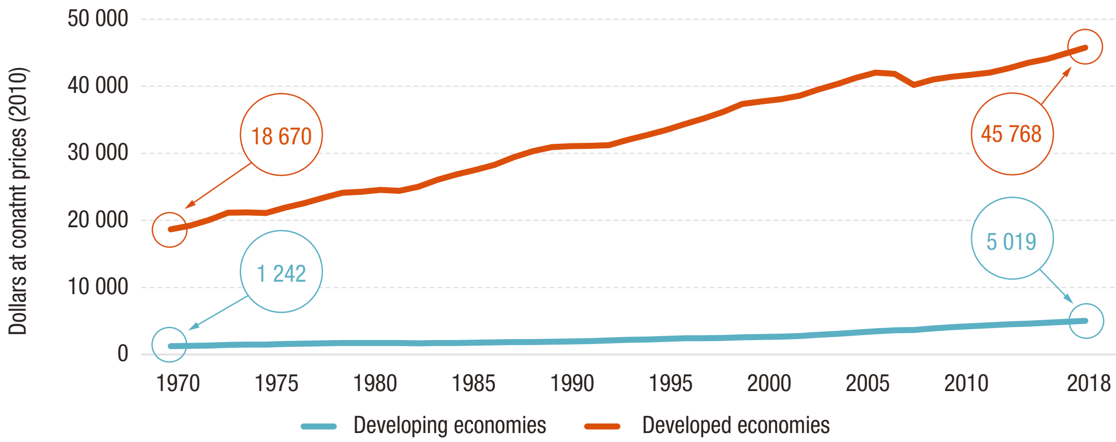
Source: UNCTAD based on Milanovic (2011).

Inequality between countries may have been falling in relative terms, but in absolute terms it has never been higher and continues to increase. For example, in 1970, the average GDP per capita in developed countries was $18,670, compared with $1,242 in developing economies (Figure I6), resulting in a gap in absolute terms of $17,428. By 2018, this gap had reached $40,749. It is true that in percentage terms, the increase was greater in developing countries than in developed countries. However, the widening absolute gap means that in the global economy there is now much more inequality in the access to goods and services.

This citizen penalty can lead to discontent and add to migration pressures. People feel that no matter how hard they try they cannot increase their general standard of living in a country that is growing slowly – and that the only way to close the income gap is to move to a country with a higher average income.

In summary, between-country inequality is the most significant contributor to global inequality, and in absolute terms, the gap between developed and developing countries has increased. For policymakers in developing and developed countries, this is a critical trend that has to be reversed.

Figure I 6
Rise of average GDP per capita in developing and developed economies



Source: UNCTAD calculations based on UNCTADstat.

D. DRIVERS OF INCOME INEQUALITY

What is causing these changes in inequalities? There is no consensus about how the dynamics of economic inequality should be interpreted. One influence is the structure of economies, along with levels of industrialization. In the mid-1950s, the economist Simon Kuznets, introduced the inverted U-curve hypothesis which suggested that under capitalist development income inequality would first rise with industrialization, then begin to decline as more workers joined the high-productivity sectors of the economy. However, others have argued that the natural state of capitalism is ever-increasing inequality, and that Kuznets misinterpreted the temporary reduction in inequality after the Second World War.[30]

Wars and epidemics have always tended to equalize, by pushing down the top of the income and wealth distribution.[31] Wars destroy the assets of the rich and reduce their incomes by higher taxation. At the same time wars kill a large share of the population, which reduces the labour supply tending to push up wages. Europe's reconstruction after the Second World War, for example, ushered in a long period of equitable growth – in probably unique and unrepeatable circumstances. Since then, growth has been slower resulting in an increase in the capital-to-income ratio. Epidemics, such as the Spanish flu or the recent outbreak of COVID-19, kill many people, reducing the supply of labour while pushing up the wages for the surviving population, keeping physical capital intact, which reduces the return to capital.

Globalization and technological change can widen income inequalities within countries, but in low-income countries they can also help reduce poverty. They have done so not only in larger countries such as China and India, but also in other countries, including many in Africa.[32] In fact, from the onset of the industrial revolution, technology and trade helped people escape from poverty in Western Europe, the United States and other countries at the core of the global economy. The subsequent divide between developed and developing countries was the result of uneven relations of trade, investment and technological learning.[33] Whether globalization or technological change facilitate or hinder catch up between countries will depend to a large extent on the policies in place.

Inequality is also affected by more dramatic technological changes which combine with financial capital to create new 'techno-economic paradigms' – the cluster of technologies, products, industries, infrastructure and institutions that characterize a technological revolution. In the countries at the centre of a technological revolution this surge can be considered in two stages, both of which affect inequalities. [34] The first is the installation period as core industries explore potential solutions with the new technologies. This can result in increasing income inequality between the workers in the

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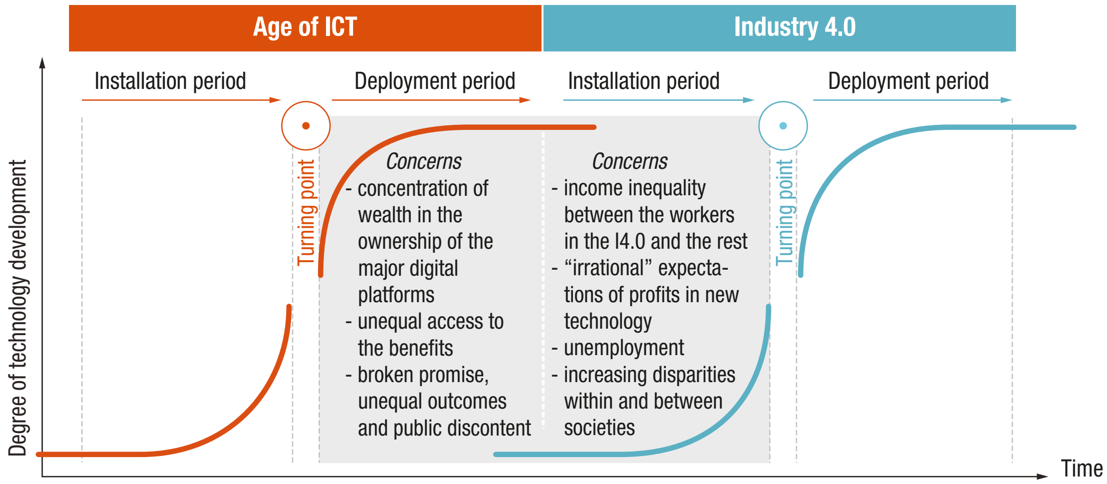
core industries of the new paradigm and the rest. In particular, the financial sector fuels "irrational" expectations of profits in new technology sectors which can decouple from the real economy in the search for increasingly higher gains. The final part of the installation period could thus be marked by stark inequalities.

The second phase is deployment. During this period more people participate in the growth of the economy. Nevertheless, the gains are not spread equally and towards the end of the deployment phase, there can therefore be rising discontent. Not everyone gets immediate access to the benefits of technological progress such as a life-saving treatment, or access to clean water, or specific knowledge, or to the wealth that is created by the development and production of new technologies.[35] At this point there are also likely to be mergers and takeovers which serve to concentrate power in few firms in the core of the paradigm, giving rise to great fortunes in the hands of a few.

The world is reaching the end of the deployment phase of the "Age of ICT" and starting the installation phase of a new paradigm sometimes called "Industry 4.0" (Figure I7). The age of ICT offered widespread progress but many of these promises were broken and the unequal outcomes have led to rising social and political discontent – which is further fuelled by the enormous concentration of wealth in the ownership of the major digital platforms. The new technologies of Industry 4.0 may also eventually widen disparities. For example, those with higher incomes tend to be the first to adopt new technologies, and this differential access creates new opportunities in areas such as education, health and employment for those already possessing an advantage, further increasing disparities within and between societies. However, this has yet to happen since the new paradigm is still in its early stages.

How will these new techno-economic paradigms affect inequalities in developing countries – and inequalities between countries? For these critical questions, the techno-economic revolutions' framework is less informative. Much will depend on whether countries are catching up, forging ahead, or falling behind – which in their turn depends on their national policies and on their involvement in international trade.

Figure I 7
Technological revolutions and inequalities



Source: UNCTAD based on Perez (2002).

E. REDUCING INEQUALITY

Within-country inequality is tackled primarily with national policies. Governments can intervene with progressive taxation on incomes and higher taxation of inheritance and wealth, or on income from capital. They can also make services such as education freely available to all which reduces the inequality of

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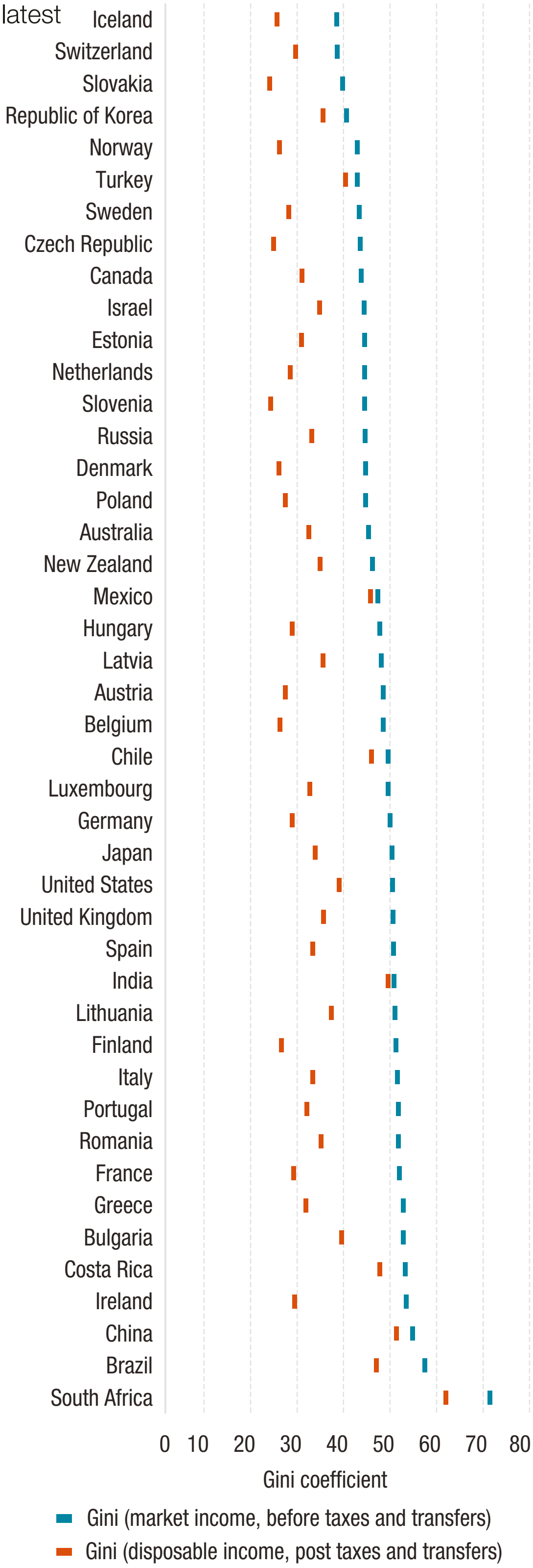
Figure I 8
Income inequality measured by the Gini of market and disposable incomes, 2017 or latest



Source: UNCTAD based on data from OECD.Stat.

opportunities. Governments can also make social transfers, such as unemployment benefits, which reduce the risk of people falling into poverty.[36] Government action can also be complemented by that of labour unions. Stronger unions help to increase wages in comparison to profits.

The effect of taxation and transfers is illustrated comparing the Gini coefficient of market income (before taxes and transfers) with that of disposable income (after taxes and transfers) (Figure I8). For all countries, the Gini is less for disposable income but there are stark contrasts between countries. For example, the United States and Germany have about the same Gini coefficient before taxes and transfers – around 0.5. But policy in Germany is more progressive and redistributive, so inequality after taxes and transfers is almost 10 points lower than in the United States.[37]

Reducing income inequality between countries will mean harnessing technology and trade for structural transformation. During the industrial revolution, technology and trade helped drive the escape from poverty of Western Europe, the United States and other countries. Nowadays technology and trade have helped reduce poverty in low-income countries, not just the large ones like China and India, but also others in Africa. But technological change and globalization can also widen inequalities between countries, depending on the policies in place.

Against this backdrop, people either try to improve their circumstances where they are living or move to somewhere more prosperous. With the Internet people are much more aware of the differences in living standards between countries and may be enticed to migrate in the pursuit of a better life.

If workers are to find better-paid jobs at home, then developing countries will have to catch up through structural transformation and faster growth. To do so, and benefit from the new paradigm they can use frontier technologies. The next chapter assesses the current state of these technologies and how ready countries are to take advantage of them.

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1 UNCTAD, 2020a
2 UNCTAD, 2018a
3 Perez, 2010; Schwab, 2013
4 Milanovic, 2016
5 Maddison, 2001
6 United Nations, 2019a
7 Coffey et al., 2020
8 Milanovic and Roemer, 2016
9 United Nations, 2020
10 UNCTAD, 2020b, 2020g
11 DESA, 2015; ESCAP, 2018
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14 Halegatte, 2014
15 Giovannini et al., 2020
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17 UNCTAD, 2012a
18 UNCTAD's Trade and Development Report 2012 provides and in-depth discussion of trends in income inequality and explores the links between income distribution, growth and development (UNCTAD, 2012a).
19 Data from the World Bank Data (GINI index, World Bank estimate). Available at https://data.worldbank.org/indicator/SI.POV.GINI?most_recent_value_desc=false (accessed 18 March 2020).
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22 More research is needed to better understand the extend of the impact of inequality on growth, given that different measures of inequality result in different scale of impact (Bartak and Jabłoński, 2019) and improvements in empirical methodologies have shown that the link between within country inequality and growth is not straightforward (Geloso, 2019).
23 Fosu, 2017
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25 IGM Forum, 2019
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37 UNCTAD based on data from OECD.Stat.

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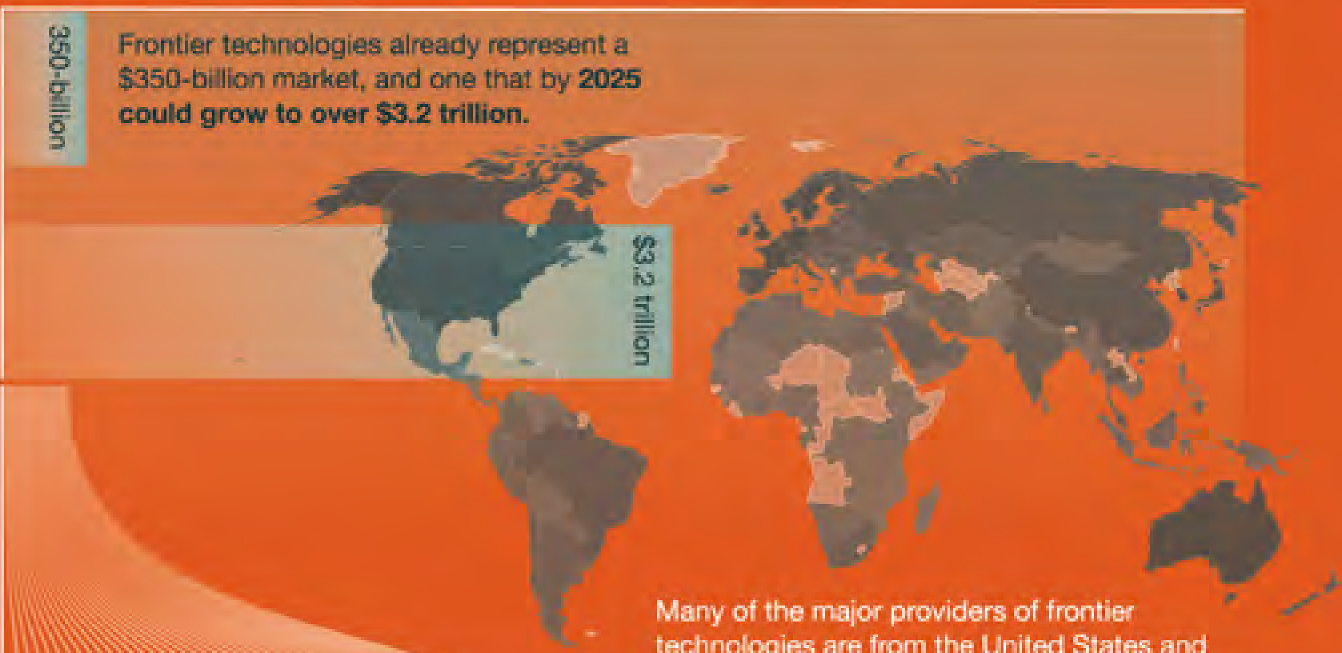
CHAPTER II

FORGING AHEAD AT THE DIGITAL FRONTIERS

Frontier technologies are new and rapidly developing technologies that take advantage of digitalization and connectivity.
This report covers 11 of these technologies:

Artificial Intelligence (AI)
The Internet of Things (IoT)
Big Data
Blockchain
5G
3D printing
Robotics
Drones
Gene Editing
Nanotech-nology
Solar Photovoltaic (Solar PV)

Frontier technologies already represent a $350-billion market, and one that by **2025 could grow to over $3.2 trillion.**



Many of the major providers of frontier technologies are from the United States and China. The countries best prepared to equitably use, adopt and adapt these technologies are the United States, Switzerland, the United Kingdom, Sweden, Singapore, the Netherlands and the Republic of Korea.

In general, the economies most ready are in Northern America and Europe while those least ready are in sub-Saharan Africa, and in the developing economies.

Developing countries need to work towards universal internet access and ensure that all their citizens have opportunities to learn the skills to be more ready for frontier technologies.

There is no single definition of frontier technologies, but they are generally understood to be new and rapidly developing technologies that take advantage of digitalization and connectivity. These technologies can have dramatic impacts on economies and societies as well as on the development of other technologies.[1] This report covers 11 such technologies: artificial intelligence (AI), the Internet of things (IoT), big data, blockchain, 5G, 3D printing, robotics, drones, gene editing, nanotechnology and solar photovoltaic (Solar PV) (Table II 1). Most of these technologies have emerged in a period of dramatic falls in the prices of data storage and solar energy.[2]

Frontier technologies can increase productivity and improve livelihoods.[3] AI, for example, combined with robotics can transform production and business. 3D printing allows faster and cheaper low-volume production and rapid iterative prototyping of new products. Using these and other innovations, enterprises in developing countries can leapfrog previous paradigms and move ahead rapidly.[4] Despite low resources and capabilities, many firms and farms are already doing so. In Nigeria, for example, IoT is being used to generate advice on farming techniques. And in Colombia 3D printers are being used to create fashion items such as caps, bracelets, and dresses.[5 6]

Table II 1
Frontier technologies covered in this report

Technology	Description
Artificial intelligence (AI)	AI is normally defined as the capability of a machine to engage in cognitive activities typically performed by the human brain. AI implementations that focus on narrow tasks are widely available today, used for example, in recommending what to buy next online, for virtual assistants in smartphones, and for spotting spam or detecting credit card fraud. New implementations of AI are based on machine learning and harness big data.
Internet of Things (IoT)	IoT refers to myriad Internet-enabled physical devices that are collecting and sharing data. There is a vast number of potential applications. Typical fields include wearable devices, smart homes, healthcare, smart cities and industrial automation.
Big data	Big data refers to datasets whose size or type is beyond the ability of traditional database structures to capture, manage and process. Computers can thus tap into data that has traditionally been inaccessible or unusable.
Blockchain	A blockchain refers to an immutable time-stamped series of data records supervised by a cluster of computers not owned by any single entity. Blockchain serves as the base technology for cryptocurrencies, enabling peer-to-peer transactions that are open, secure and fast.
5G	5G networks are the next generation of mobile internet connectivity, offering download speeds of around 1-10 Gbps (4G is around 100 Mbps) as well as more reliable connections on smartphones and other devices.
3D printing	3D printing, also known as additive manufacturing, produces three-dimensional objects based on a digital file. 3D printing can create complex objects using less material than traditional manufacturing.
Robotics	Robots are programmable machines that can carry out actions and interact with the environment via sensors and actuators either autonomously or semi-autonomously. They can take many forms: disaster response robots, consumer robots, industrial robots, military/security robots and autonomous vehicles.
Drones	A drone, also known as unmanned aerial vehicle (UAV) or unmanned aircraft systems (UAS), is a flying robot that can be remotely controlled or fly autonomously using software with sensors and GPS. Drones have been often used for military purposes, but they also have civilian uses such as in videography, agriculture and in delivery services.
Gene editing	Gene editing, also known as genome editing, is a genetic engineering tool to insert, delete or modify the genome in organisms. Potential applications include drought-tolerant crops or new antibiotics.
Nanotechnology	Nanotechnology is a field of applied science and technology dealing with the manufacturing of objects in scales smaller than 1 micrometre. Nanotechnology is used to produce a wide range of useful products such as pharmaceuticals, commercial polymers and protective coatings. It can also be used to design of computer chip layouts.
Solar photovoltaic (Solar PV)	Solar photovoltaic (Solar PV) technology transforms sunlight into direct current electricity using semiconductors within PV cells. In addition to being a renewable energy technology, solar PV can be used in off-grid energy systems, potentially reducing electricity costs and increasing access.

Source: UNCTAD.

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A number of studies have analysed the effects of these technologies separately, or in smaller groups (e.g. AI, big data, and IoT), or on different dimensions of inequality.[7] [8] This report aims for a broader appreciation of the impact of frontier technologies on inequalities so has assessed them as a larger group. Such a synthesis can create new knowledge, help generalize the findings of separate studies and guide evidence-informed decision making.[9]

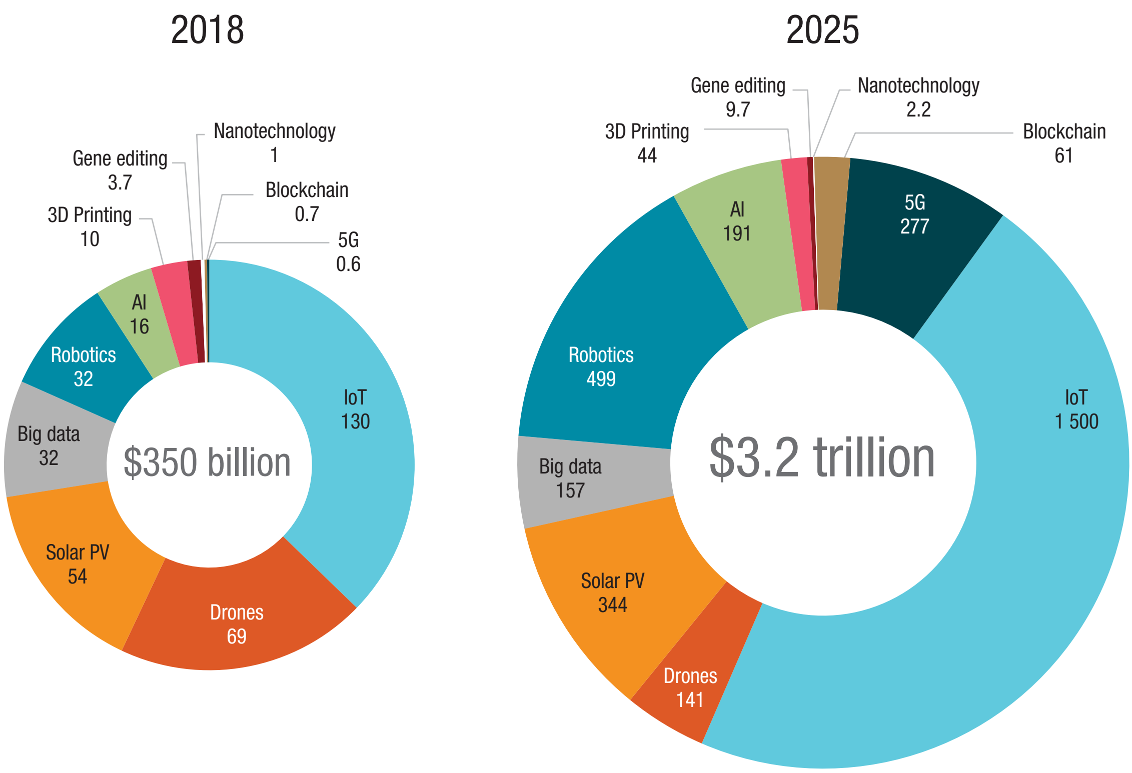
A. RAPID GROWTH OF FRONTIER TECHNOLOGIES

According to some estimates, frontier technologies already represent a $350-billion market, and one that by 2025 could grow to over $3.2 trillion (Figure II 1). To put this into perspective, the current global market for laptops is $102 billion and for smartphones is $522 billion. Some estimates for frontier technologies may be over-hyped, and there may also be considerable double counting, for example in IoT which is also based on AI and big data, but market analysts clearly have high expectations.

Among the frontier technologies, the largest by market revenue is IoT. In 2018, sales totalled $130 billion,[10] and in the next five years could grow to $1.5 trillion – which is around half of frontier technology revenues.[11] This is because IoT covers such a vast range of devices: in 2017 there were already more IoT devices in use than people on earth – 8.4 billion. Another area of future expansion is the industrial internet of things (IIoT) which uses multiple interconnected devices for various forms of manufacturing, for the Airbus and Boeing factories of the future, for example, or Amazon's warehousing, or for agriculture for self-driving tractors.[12]

The market for robotics is also set to expand rapidly, from $32 billion in 2018 to $499 billion in 2025.[13] On the supply side, this growth is driven mainly by continued technical improvements and

Figure II 1
Market size estimates of frontier technologies, $billions



Source: UNCTAD based on data estimates from Froese (2018), MarketsandMarkets (2018), Sawant and Kakade (2018), Business Wire (2019), Chaudhary et al. (2019), GlobeNewswire (2019b), MarketsandMarkets (2019), MarketWatch (2019a), MarketWatch (2019i), Raza (2019), Tewari and Baul (2019), Wagner (2019b), Mordor Intelligence (2020a).

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the development of AI-enabled self-programming robots.[14] On the demand side, growth will come from the use of robots in large-scale manufacturing, packaging, and the automobile industry. But even some small and medium-scale enterprises that are facing higher labour costs or cannot recruit enough skilled workers are adopting industrial robots.[15]

Another expanding market is for solar PV. In 2018 market revenues were $55 billion and by 2026 may reach $334 billion.[16] This is driven by increasing energy demand, favourable government regulation and a shift towards sustainable consumption which has encouraged the use of renewable energy.[17] As indicated in Figure II 1, there will probably be a similar rapid growth in other frontier technologies.[18]

Rapid market growth will also create more frontier-technology-related jobs:

- *AI* – Between June 2015 and June 2018, job offers for AI-related posts on a worldwide employment search engine increased by nearly 100 per cent.[19] The greatest increase was for software engineers and data scientists. A study in 2019 found that China had the most AI professionals, with 12,113 jobs, followed by the United States at 7,465 and Japan at 3,369.[20]
- *Blockchain* – Between 2017 and 2018 the demand for blockchain engineers in the United States grew by 400 per cent.[21] The average income of a blockchain engineer reached $150,000-$175,000 per year.[22] Facebook, Amazon, IBM and Microsoft are all recruiting talent in this field.[23]
- *Drones* – Between 2013 and 2025 the United States is expected to add more than 100,000 drone-related jobs.[24] The top three drone job locations are the United States, China and France.[25]
- *5G* – By 2035, the global 5G value chain is expected to support 22 million jobs. This includes employment in network operators, core technology and components providers, OEM device manufacturers, infrastructure equipment manufacturers and content and application developers. China may have the most 5G-related jobs (9.5 million) followed by the United States (3.4 million) and Japan (2.1 million).[26]
- *3D printing* – The market is growing rapidly, stimulating the demand for skilled professionals, including engineers, software developers, material scientists and a wide range of business support functions including sales and marketing.[27]
- *Gene editing* – Labour demand in gene editing is also expected to soar. Between 2017 and 2030, the United Kingdom may add 18,000 new jobs.[28] Between 2016 and 2026, the United States could add 17,600 jobs including medical scientists and biomedical engineers.[29]
- *IoT* – By 2017 the global IoT industry had grown to 2,888 companies employing around 342,000 people.[30] The largest number of IoT-related jobs were in IBM (4,420), Intel Corporation (3,044), Microsoft (2,806), Cisco (2,703) and Ericsson (1,665).[31]
- *Big data* – As more industries have started to adopt big data there has been a significant shortage of data scientists. In the United States, as of 2018, there was a shortage of 151,717 people with a data science background, especially in New York City (34,032), the San Francisco Bay Area (31,798) and Los Angeles (12,251).[32]
- *Robotics* – Robotics careers include robotics engineers, software developers, technicians, sales engineers and operators.[33] In 2016, the United States had 132,500 robotics engineers, and between 2016 and 2026 the robotics engineer job market was expected to grow by 6.4 per cent.[34]
- *Nanotechnology* – The job market in the United States is set to grow by 6 per cent per year between 2016 and 2026.[35] The expected salaries range between $35,000 and $50,000 for graduates with associated degrees to $75,000-$100,000 for those with doctoral degrees.[36]
- *Solar PV* – Jobs are set to grow at a rapid pace, but as yet there is little evidence of a solar hiring boom. The recent political and industry turbulence on solar energy has slowed growth.[37]

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Table II 2
Sectors that were early adopters of frontier technology

AI	IoT	Big data	Blockchain	5G
Retail	Consumer	Finance	Finance	Utilities
Finance	Finance	Manufacturing	Manufacturing	Manufacturing
Manufacturing	Healthcare	Professional services	Retail	Public safety

3D printing	Robotics	Drones	Gene editing	Nanotechnology	Solar PV
Manufacturing	Manufacturing (discrete)	Utilities	Pharma/biotech	Medicine	Residential
Healthcare	Manufacturing (process)	Construction	Academic/ research	Manufacturing	Commercial
Education	Resource	Manufacturing	Agrigenomic	Energy	Utilities

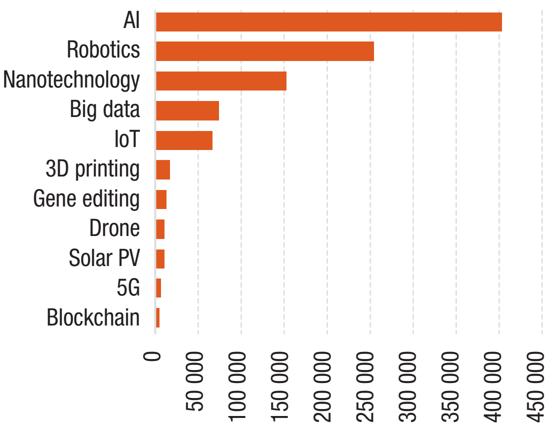
Source: UNCTAD based on data on AI (IDC, 2019c), IoT (Business Wire, 2018), Big data (IDC, 2019d), blockchain (IDC, 2019b), 5G (Reichert, 2017), 3D printing (IDC, 2019a), robotics (IDC, 2018), drones (IDC, 2018), gene editing (GlobeNewswire, 2019a), nanotechnology (Cox, 2019; Nano.gov, 2020), and Solar PV (Doshi, 2017).
Notes: The finance sector is shown in blue, the manufacturing sector in orange and others in grey.

The finance and manufacturing sectors were early adopters of AI, IoT, big data and blockchain (Table II 2). Finance companies have used these technologies, for example, for credit decisions, risk management, fraud prevention, trading, personalized banking and process automation.[38] The manufacturing sector has used these technologies for predictive maintenance, quality control and human-robot combined working activities.[39]

Major providers of frontier technology are shown in Table II 3. Many are from the United States, probably because the United States is home to major cloud computing platforms. For AI, IoT, big data, blockchain and other activities these platforms offer a wide range of one-stop services on a pay-as-you-go basis. This concentration on large platforms is likely to continue. Users prefer not to build their own systems from scratch, and because of existing network effects new competitors struggle to catch up.[40] Chinese companies are very active in 5G, drones and solar PV.[41]

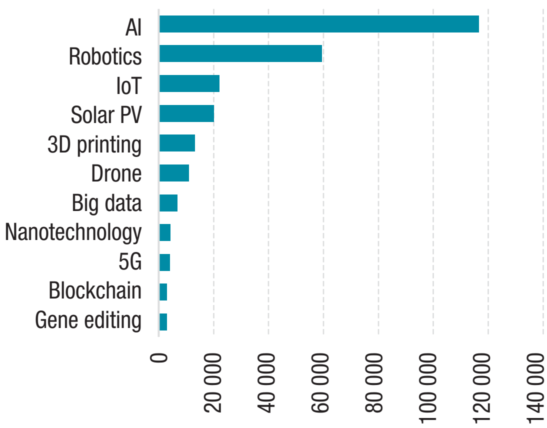
The development of frontier technologies has generated a large number of publications and patents (Figure II 2 and Figure II 3). The two major players are the United States and China, together holding a 30 to 70 per cent share in each technological field (Figure II 4 and Figure II 5). The United States is especially active in robotics, gene editing and blockchain while China is active in IoT, big data and solar PV.[42]

Figure II 2
Number of publications by frontier technology



Source: UNCTAD calculations based on data from Scopus.

Figure II 3
Number of patents by frontier technology



Source: UNCTAD calculations based on data from PatSeer.

Table II 3
Top frontier technology providers

AI	IoT	Big data	Blockchain	5G
Alphabet	Alphabet	Alphabet	Alibaba	Ericsson
Amazon	Amazon	Amazon Web Services	Amazon Web Services	Huawei (network)
Apple	Cisco	Dell Technologies	IBM	Nokia
IBM	IBM	HP Enterprise	Microsoft	ZTE
Microsoft	Microsoft	IBM	Oracle	Huawei (chip)
	Oracle	Microsoft	SAP	Intel
	PTC	Oracle		MediaTek
	Salesforce	SAP		Qualcomm
	SAP	Splunk		Samsung Electronics
		Teradata		

3D printing	Robotics	Drones	Gene editing	Nanotechnology	Solar PV
3D Systems	ABB	3D Robotics	CRISPR Therapeutics	BASF	Jinko Solar
ExOne Company	FANUC	DJI Innovations	Editas Medicine	Apeel Sciences	JA Solar
HP	KUKA	Parrot	Horizon Discovery Group	Agilent	Trina Solar
Stratasys	Mitsubishi Electric	Yuneec	Intellia Therapeutics	Samsung Electronics	Canadian Solar
	Yaskawa	Boeing	Precision BioSciences	Intel	Hanwa Q cells
	Hanson Robotics	Lockheed Martin	Sangamo Therapeutics		
	Pal Robotics	Northrop Grumman			
	Robotis				
	Softbank Robotics				
	Alphabet/Waymo				
	Aptiv				
	GM				
	Tesla				

Source: UNCTAD based on data on AI (Ball, 2017; Patil, 2018; Botha, 2019), IoT (DA-14, 2018; J. Lee, 2018; Rana, 2019), Big data (Verma, 2018; MarketWatch, 2019a; SoftwareTestingHelp, 2020), blockchain (Akilo, 2018; Patrizio, 2018; Anwar, 2019), 5G (Auchard and Nellis, 2018; La Monica, 2019; Whatsag, 2020), 3D printing (Vanakuru, 2018; Neufeld, 2019; Wagner, 2019a), Robotics (MarketWatch, 2018a; Technavio, 2018b; Yuan, 2018; Mitrev, 2019; The Express Wire, 2019; Mordor Intelligence, 2020b), Drone (Technavio, 2018a; FPV Drone Reviews, 2019; Joshi, 2019), Gene editing (Schmidt, 2017; Philippidis, 2018; Acharya, 2019), nanotechnology (Venture Radar, 2020), Solar PV (Infiniti Research, 2017; Lapping, 2017; Zong, 2019).

Notes: American companies in blue, Chinese companies in orange and others in grey.

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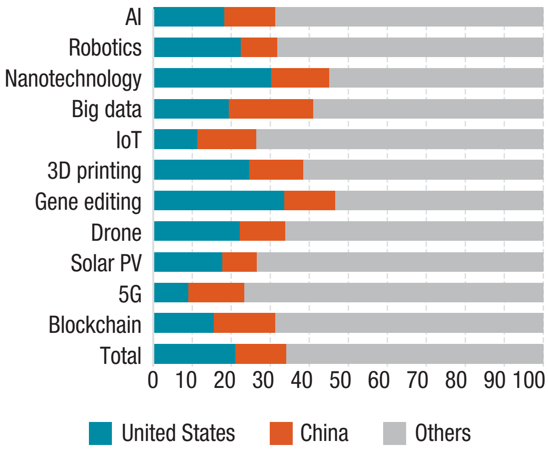
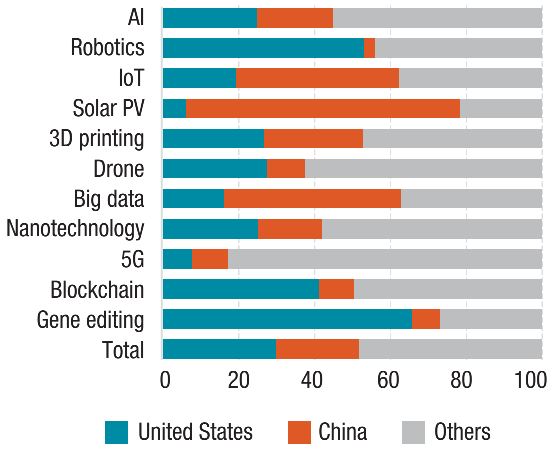
Figure II 4
Country share of publications by frontier technology (percentage)



Source: UNCTAD calculations based on data from Scopus.

Figure II 5
Country share of patents by frontier technology (percentage)



Source: UNCTAD calculations based on data from PatSeer.

Table II 4 presents a summary of key indicators of the frontier technologies covered in this report. References and further information are presented in Annex B. Frontier technology trends.

B. A FRONTIER TECHNOLOGIES READINESS INDEX

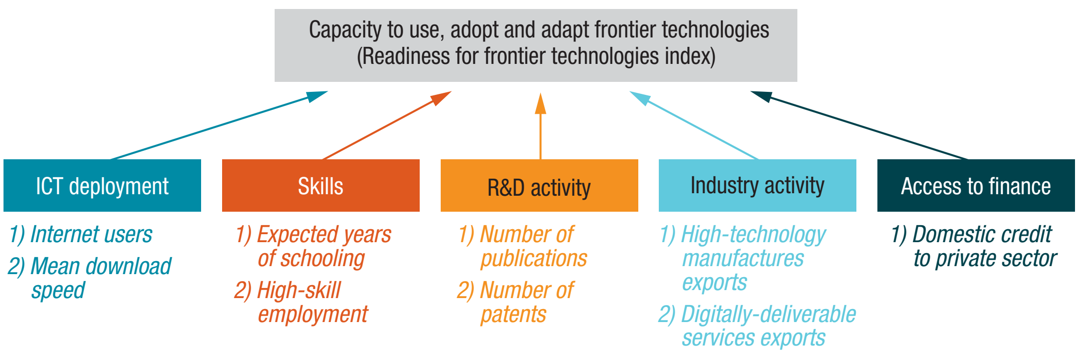
Only a few countries currently produce frontier technologies and in the short run this is unlikely to change. But all countries need to prepare for them. To assess progress this report has developed a country readiness index. This takes into account technological capacities related to physical investment, human capital and technological effort, and covers national capacities to use, adopt and adapt these technologies:[43]

Use – This requires basic capacities, passive skills and effort along with infrastructure, and some technological knowledge. This might involve, for example, following AI-driven recommendation from an e-commerce website, or using a chatbot.

Adopt – Active use for one's own purposes requires more advanced capability levels. This could mean using AI to produce recommendations or run a chatbot for a business website.

Adapt – Modifying the technologies requires further advanced capabilities – such as for tailoring AI-driven recommendations or localizing the features of a chatbot.

Figure II 6
Structure of the readiness index



Source: UNCTAD.

Table II 4
Key indicators

Technology	Artificial intelligence (AI)	Internet of Things (IoT)	Big data	Blockchain	3D printing	Robotics
Publications (1996-2018)	403,596	66,467	73,957	4,821	17,039	254,409
Patents (1996-2018)	116,600	22,180	6,850	2,975	13,215	59,535
Price	Insurance fraud-detection tool: $100,000–$300,000, Chatbots: $30,000–$250,000	Electro-cardiography monitors: $3,000–$4,000 Building and home automation: from $50,000	Building and maintaining a 40-terabyte data warehouse: $880,000 per year	Development of a project: $5,000–$200,000	Entry level 3D printer: $200, top-notch industrial printer: $100,000, average 3D printer: $700	Industrial robots: $25,000-$400,000, humanoids: $500–$2,500,000
Market size	$16 billion (2017) $191 billion (2024)	$130 billion (2018) $1.5 trillion (2025)	$32 billion (2017) $157 billion (2026)	$708 million (2017) $61 billion (2024)	$10 billion (2018) $44 billion (2025)	$32 billion (2018) $499 billion (2025)
Major providers	Alphabet, Amazon, Apple, IBM, Microsoft	Alphabet, Amazon, Cisco, IBM, Microsoft, Oracle, PTC, Salesforce, SAP (IoT platform)	Alphabet, Amazon, Dell, HP, IBM, Microsoft, Oracle, SAP, Splunk, Teradata (storage platforms, analytics)	Alibaba, Amazon, IBM, Microsoft, Oracle, SAP (blockchain-as-a-service)	3D Systems, ExOne, HP, Stratasys	ABB, FANUC, KUKA, Mitsubishi Electric, Yaskawa (industrial robots) Hanson Robotics, Pal Robotics, Robotis, Softbank Robotics (humanoids) Alphabet/ Waymo, Aptiv, GM, Tesla (autonomous vehicles)
Major users	Retail, banking, discrete manufacturing	Consumer, insurance, health-care providers	Banking, discrete manufacturing, professional services	Finance, manufacturing, retail	Discrete manufacturing, healthcare, education	Discrete manufacturing, process manufacturing, resource industry

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Table II 4
Key indicators

Technology	Drones	Gene editing	5G	Nanotechnology	Solar photovoltaic (Solar PV)
Publications (1996-2018)	10,979	12,947	6,828	152,359	10,768
Patents (1996-2018)	10,897	2,899	4,161	4,293	20,074
Price	Commercial drones: $50–$300,000 (high-end: $1000–$4000), Military drones: $14.5 million (MQ-9 Reaper)	Standard in vitro fertilization: over $20,000/try + $10,000 or more for tests	$0–20/month more than 4G network	Anti-cancer drug with nanotechnology: $4,363/cycle	Residential PV system (6kW): $16,200–$21,420
Market size	$69 billion(2017) $141 billion (2023)	$3.7 billion (2018) $9.7 billion (2025)	$608 million (2018) $277 billion (2025)	$1 billion (2018) $2.2 billion (2025)	$54 billion (2018) $334 billion (2026)
Major providers	3D Robotics, DJI Innovations, Parrot, Yuneec (commercial drones) Boeing, Lockheed Martin, Northrop Grumman Corporation (military drones)	CRISPR Therapeutics, Editas Medicine, Horizon Discovery Group, Intellia Therapeutics, Precision BioSciences, Sangamo Therapeutics	Ericsson, Huawei, Nokia, ZTE (network equipment) Huawei, Intel, MediaTek, Qualcomm, Samsung Electronics (chip)	BASF, Apeel Sciences, Agilent, Samsung Electronics, Intel	Jinko Solar, JA Solar, Trina Solar, Canadian Solar, Hanwha Q cells
Major users	Utilities, construction, discrete manufacturing	Pharma-biotech, academic/ research centre, agrigenomic/ contract research organizations	Energy utilities, manufacturing, public safety	Medicine, manufacturing, energy	Residential, Commercial, Utilities

Source: See Annex B. Frontier technology trends.
Notes: Publication and patent data are from the period 1996-2018. Market size data are rounded.

The index comprises five building blocks: ICT deployment, skills, R&D activity, industry activity and access to finance (Figure II 6).[44] The index was calculated for 158 countries. The technical details on composing and calculating the index can be found in the Statistical Appendix. Readiness for frontier technologies index.

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Based on this index, the countries best prepared are the United States, Switzerland and the United Kingdom (Table II 5). Other than the United States, Singapore and the Republic of Korea, most of the leading countries are from Europe. The list also has high rankings for some transition and developing economies – such as China ranked at 25 and the Russian Federation at 27.

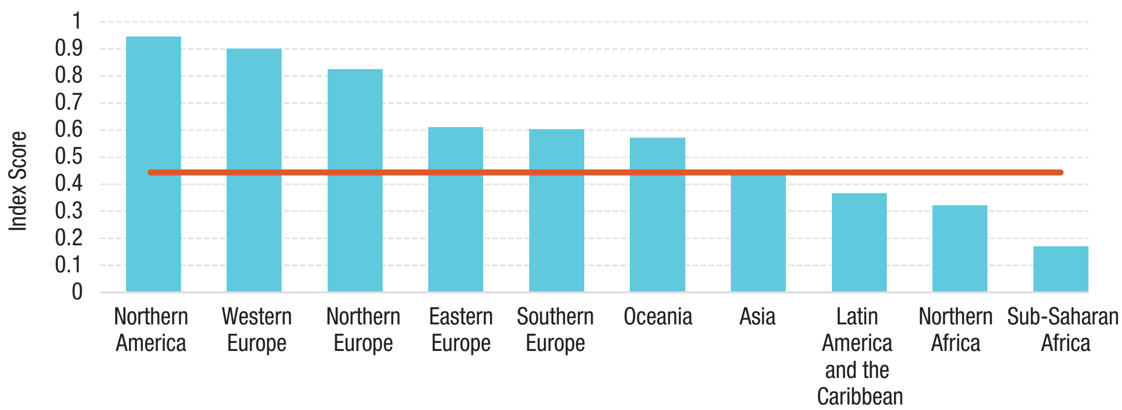
Table II 5
Readiness towards the use, adoption and adaptation of frontier technologies, selected countries

Country name	Total ranking	ICT ranking	Skills ranking	R&D ranking	Industry ranking	Finance ranking
Top 10						
United States of America	1	14	17	2	20	2
Switzerland	2	7	13	13	3	3
United Kingdom	3	17	12	6	11	14
Sweden	4	1	7	16	15	16
Singapore	5	4	9	18	4	18
Netherlands	6	6	10	15	8	23
Korea, Republic of	7	19	27	3	9	8
Ireland	8	24	6	21	1	87
Germany	9	23	16	5	10	39
Denmark	10	2	4	25	21	5
Selected transition and developing economies						
China	25	99	96	1	7	6
Russian Federation	27	39	28	11	66	45
Brazil	41	73	53	17	42	60
India	43	93	108	4	28	76
South Africa	54	69	84	39	71	13

Source: UNCTAD (see the complete table in Statistical Appendix. Readiness for frontier technologies index).

In general, the economies most ready are in Northern America and Europe while those least ready are in sub-Saharan Africa (Figure II 7), and in the developing economies generally (Figure II 8).

Figure II 7
Average index score by geographical group



Source: UNCTAD.

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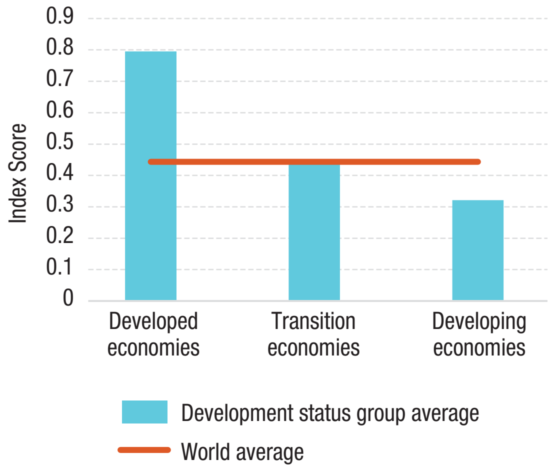
Not surprisingly, the countries most ready for frontier technologies are also those most likely to use them. This is clear in the case of solar PV where there is a strong correlation between the readiness index and solar PV electricity capacity (Figure II 9). Similarly, it is possible to correlate the index with the import of industrial robots and of nanomaterials, but most of the other technologies are difficult to isolate since they can be embedded in such a diverse range of products.

The index rankings might also be expected to correlate with those for per capita income, and generally they do (Figure II 10). This could be explained in two ways: countries with higher per capita incomes are more likely to have higher figures for ICT deployment, skills, R&D activity, industry activity and access to finance – because they have more resources and capacities to make investments and implement policies. On the other hand, high performance in these areas will itself boost productivity and per capita incomes. However, it should be noted that per capita income is only one factor associated with the readiness index, others include policies, institutions, factor endowments and even historical contexts.

But there are clearly many outliers – countries that perform better than their per capita GDPs would suggest. The extent of "overperformance", measured as the difference between the actual index rankings and the estimated index rankings based on per capita income, is indicated in (Table II 6). The greatest overperformer is India, by 65 ranking positions, followed by the Philippines by 57.

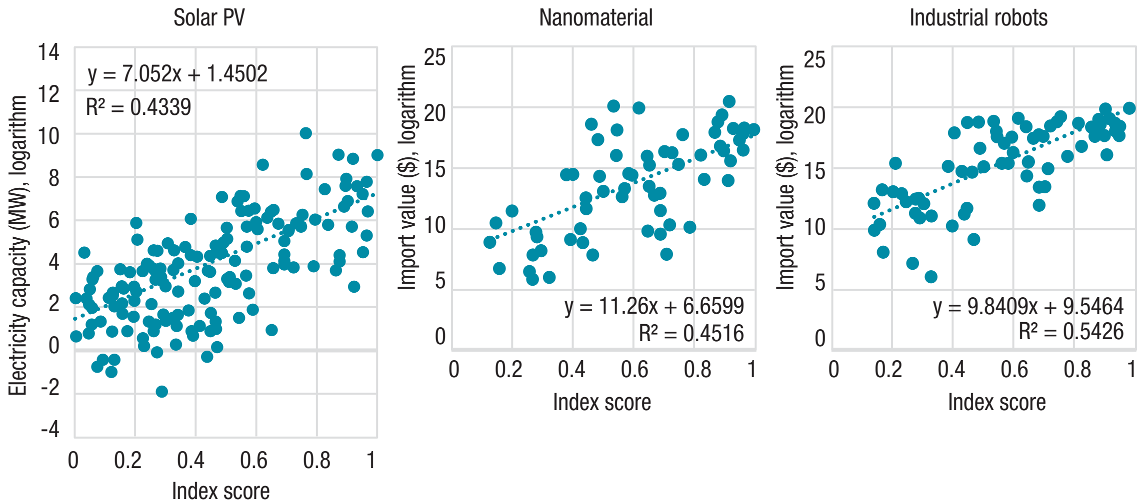
How have these countries performed so well? This can be explained by looking more closely at how they performed on the index's individual building blocks. Figure II 11 shows the rankings by block of selected top overperforming developing countries.

Figure II 8
Average index score by development status



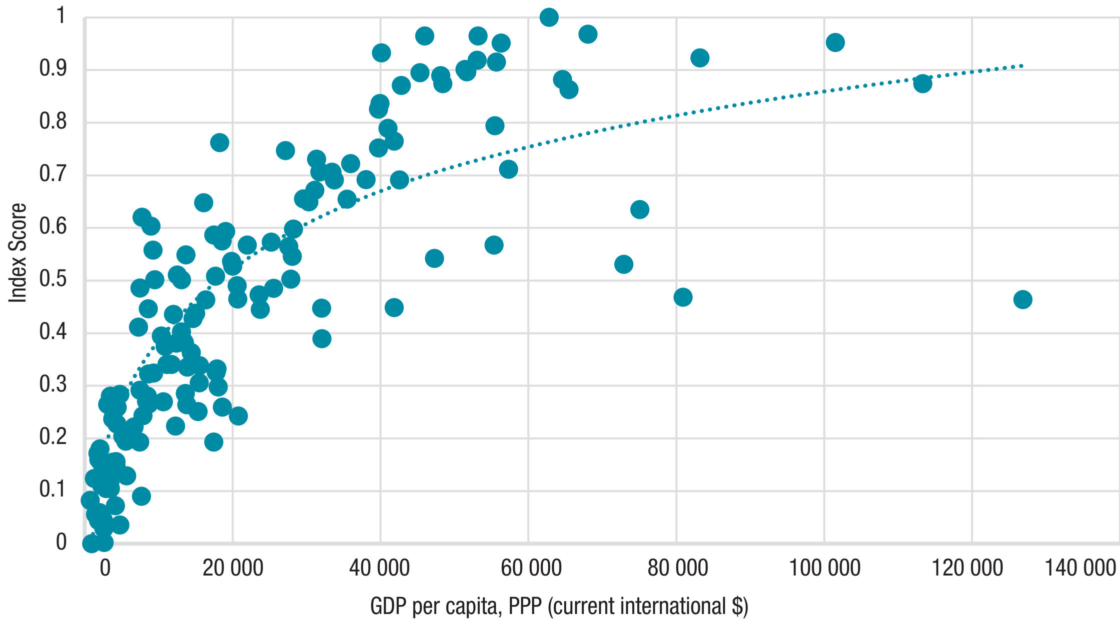
Source: UNCTAD.

Figure II 9
Correlation between the index score and the adoption of selected frontier technologies, 2018



Source: UNCTAD based on data from UN COMTRADE and IRENA (2020).
Notes: Data on import of industrial robots refer to the import of "Machinery and mechanical appliances; industrial robots, n.e.c. or included" under HS code 847950. Import of nanomaterial relates to import of "Inorganic or organic compounds of precious metals, n.e.c.; amalgams" classified under HS 284390. The correlation in the three graphs is statistically significant at 0.01 level ($p < .001$).

Figure II 10
Correlation between index score and GDP per capita, average 2017-2019



Source: UNCTAD calculations based on GDP data by the World Bank (World Bank, 2020).
Note: The correlation is statistically significant at 0.01 level ($p < .001$).

China and India perform well for R&D. This reflects their abundant supplies of qualified and highly skilled human resources available. They also have large local markets, which attract investment by multinational enterprises.[45] In the case of China the progress is partly a reward for spending 2 per cent of GDP on R&D.[46]

Table II 6
Countries overperforming relative to per capita GDP, gain in ranking position

	Country	Overperformance (positions)		Country	Overperformance (positions)
1	India	65	11	Morocco	29
2	Philippines	57	12	Kenya	28
3	Ukraine	47	13	Nepal	28
4	Viet Nam	45	14	Serbia	25
5	China	40	15	Korea, Republic of	24
6	Jordan	34	16	Russian Federation	24
7	Brazil	33	17	Lebanon	24
8	Republic of Moldova	33	18	Togo	23
9	South Africa	29	19	United Kingdom	21
10	Tunisia	29	20	Ghana	20

Source: UNCTAD calculations based on GDP data by the World Bank (World Bank, 2020).
Note: Overperformance by gain in ranking position are measured taking the difference in positions between the actual index rankings and the estimated index rankings based on per capita income. For instance, India's actual index ranking was 43 while the estimated index ranking based on per capita income was 108. Hence, India overperformed by 65 ranking positions.

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Jordan also does well, again reflecting supportive government policy. Jordan was one of the first Arab countries to support ICT as a standalone economic sector and from 1999 had the first nationwide ICT strategy. Jordan now has a young, digitally literate population and high Internet penetration.[47]

The Philippines has a high ranking for industry. This reflects high levels of FDI in high-technology manufacturing, particularly electronics. MNEs are attracted by the country's strong supply chains and solid base of parts manufacturing. The Philippines also has pro-business policies along with a skilled, and English-speaking workforce, and a network of economic zones.[48]

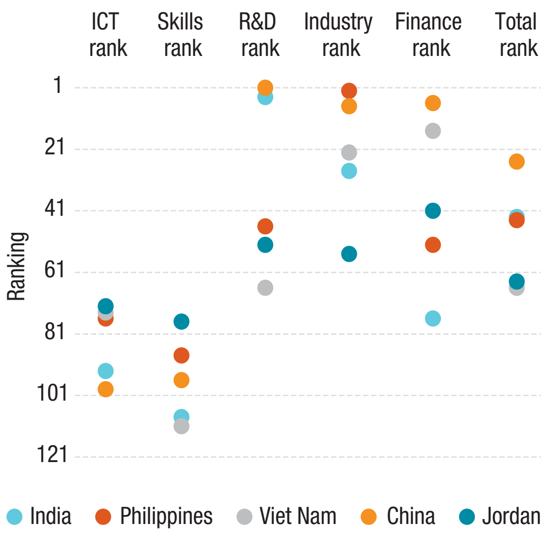
Developing countries need to work towards universal internet access and ensure that all their citizens have opportunities to learn the skills to be more ready for frontier technologies

Viet Nam has been successful in increasing its technological and productive capabilities to further industrialize its economy. Between 2005 and 2018, the proportion of exports made up of primary and resource-based goods fell from 52 per cent to 22 per cent, while those of high-tech goods rose from 6 per cent to 35 per cent.[49] The drive for industrialization started in the 1990s. Export-led growth was promoted through a mixture of import substitution measures and export subsidies. This encouraged inflows of FDI. Since 2000, the new Enterprise Law has made it easier and faster for businesses to register. Production has also been transformed through the establishment of export processing zones and industrial zones, as well the development of urban infrastructure and human resources.[50]

Overall, however, these top overperforming developing countries have lower rankings for ICT connectivity and skills. This is true for the developing countries as a group (Figure II 12). By contrast, the top five in the overall readiness ranking tend to have well-balanced performances across all building blocks (Figure II 13).

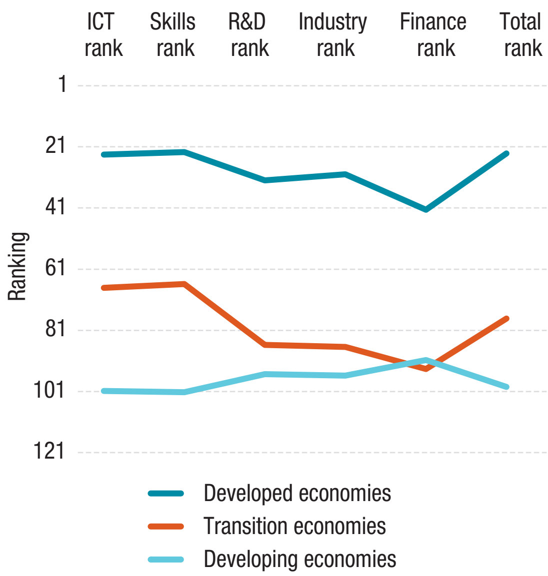
One implication of this result is that developing countries need to work towards universal internet access and ensure that all their citizens have opportunities to learn the skills to be more ready for frontier technologies. At present there are generally wide urban-rural disparities. For example, in 2018 in China,

Figure II 11
Index ranking by building block (selected top overperforming developing countries)



Source: UNCTAD.

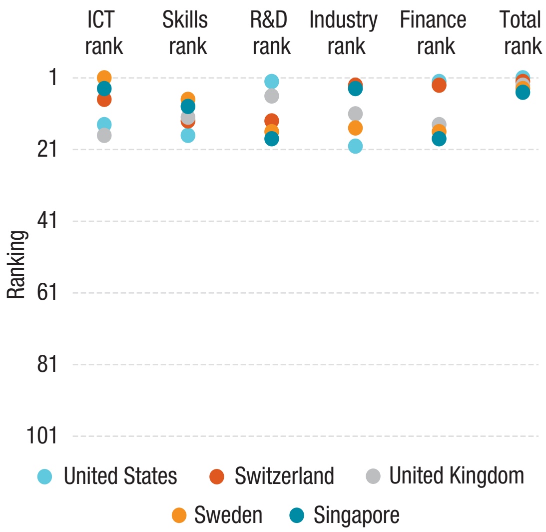
Figure II 12
Average index ranking by building block (developed, transition and developing economies)



Source: UNCTAD.

Figure II 13

Index ranking by building block (top 5 countries by total ranking)



Source: UNCTAD.

Internet coverage in urban areas was 75 per cent, comparable with that of Portugal and Poland, while in the rural areas the coverage was just 38 per cent, similar to that of Cambodia and Côte d'Ivoire.[51] To tackle this challenge in 2015, the Chinese State Council announced it would invest $22 billion by 2020 to provide rural areas with broadband access.[52]

***

Frontier technologies offer a window of opportunity for developing countries to increase productivity and improve livelihoods. But technological change, which is now driven mainly by developed countries, could also widen the gaps between countries and make it even more difficult to catch up in terms of production or consumption. Also, frontier technologies could transform jobs and labour markets with profound implications for societies as a whole. The next chapter looks at this issue more closely.

1 UNCTAD, 2018a; United Nations, 2018b

2 UNCTAD, 2018, 2019a; Fagerberg and Verspagen, 2020

3 Ramalingam et al., 2016; UNCTAD, 2018a; United Nations, 2019a

4 UNCTAD, 2018b

5 Cuipa et al., 2018; M. Gray and Suri, 2019

6 The *Technology and Innovation Report 2018* presents several examples and discusses ways of harnessing frontier technologies for sustainable development (UNCTAD, 2018a).

7 UNCTAD, 2016a; Gyngell et al., 2017; Ali et al., 2019; Simonstein, 2019

8 Autor, 2015; Acemoglu and Restrepo, 2017, 2018; Lutz, 2019

9 Snilstveit et al., 2012; Wyborn et al., 2018

10 Froese, 2018

11 Lueth, 2018

12 Buntz, 2020

13 Wagner, 2019b; Mordor Intelligence, 2020a

14 MarketWatch, 2019c; Mordor Intelligence, 2020a

15 Transparency Market Research, 2018; MarketWatch, 2019c

16 Chaudhary et al., 2019

17 Chaudhary et al., 2019; Fortune Business Insights, 2019

18 There are huge prospects for further growth in the period from 2017-2018 to 2024-2025: AI (from $16.06 billion in 2017 to $191 billion in 2024) (MarketsandMarkets, 2018; MarketWatch, 2019i), Big data (from $31.93 billion to $156.72 billion) (MarketWatch, 2019a), blockchain (from $708 million to $60.7 billion) (MarketWatch, 2019g), 5G (from $608.3 million to be $277 billion) (Raza, 2019) (Business Wire, 2019; Raza, 2019), 3D printing (from $9.9 billion to $44.39 billion) (Sawant and Kakade, 2018; MarketsandMarkets, 2019), gene-editing (from $3.7 billion to $9.7 billion) (GlobeNewswire, 2019b), and nanotechnology (from $1.06 billion to $2.23 billion) (Tewari and Baul, 2019).

19 Overmyer, 2018

20 Rayome, 2019

21 Rodriguez, 2018

22 Hired, 2020

23 Rodriguez, 2018

24 Jenkins and Vasigh, 2013

25 Radovic, 2019

26 Campbell et al., 2017

27 Bunger, 2018

28 Thompson, 2017

29 Bureau of Labor Statistics, U.S. Department of Labor, 2019a, 2019b

30 Bjorlin, 2017

31 Buntz, 2017

32 LinkedIn, 2018

33 Grad School Hub, 2020

34 CareerExplorer, 2020a

35 CareerExplorer, 2020b

36 Peterson’s, 2017

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37 Chamberlain, 2018

38 Bachinskiy, 2019

39 Seebo 2020

40 UNCTAD, 2019a

41 Auchard and Nellis, 2018; La Monica, 2019; Whatsag, 2020; Technavio, 2018a; FPV Drone Reviews, 2019; Joshi, 2019; Infiniti Research, 2017; Lapping, 2017; Zong, 2019.

42 Analysis using number of patents has many limitations. One problem is strategic patenting as a business strategy by big companies, which blurs the usefulness of numbers of patents as an indicator. And the practice and policy on "patent quality" differs greatly between major patent offices.

43 Lall, 1992

44 The first three are aligned with the national technological capacities identified by (Lall, 1992): physical investment (ICT deployment), human capital (skills), technological effort (R&D). Industry activity is related to the assumption that the development of technological capabilities are path-dependent and based on existing capabilities (Hidalgo et al., 2007); thus the current pattern of industrial activity could inform the likelihood of adoption of frontier technologies. Access to finance is considered a building block for innovations, based on a Schumpeterian view of the finance/innovation nexus (Schumpeter, 1980, 2008).

45 Patra, 2017

46 UNESCO, 2020c: 1

47 Oxford Business Group, 2016

48 Oxford Business Group, 2018

49 UNCTADstat available from https://unctadstat.unctad.org/EN/Index.html.

50 UN-Habitat, 2015

51 CSIS China Power Team, 2019

52 CSIS China Power Team, 2019

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CHAPTER III

HUMANS AND MACHINES AT WORK

This chapter considers the impact of frontier technologies on inequalities through the production's lens.

Technological change impacts inequalities through its effect on jobs, wages and profits.

The channels of impact of frontier technologies are not different from previous technologies, but each wave of technological change brings inequality in new shapes.

Today, major concerns are related to risks of:

- Automation taking jobs in large scale
- Job polarization
- The gig economy and the reduction of labour rights
- The inequalities created by market and profit concentration
- Increase of inequality driven by AI
- Widening technological gaps

Developing countries face particular challenges:

- Demographic changes
- Existing technological gaps
- Low economic diversification
- Weak financing mechanism
- Stringent intellectual property rights

To benefit from frontier technologies, countries need to promote their use, adoption and adaptation, while addressing their potential adverse effects.

This chapter discusses the impact of frontier technologies on labour markets and jobs, and the consequences for inequalities within and between countries.[1] In many respects, frontier technologies have effects similar to those of earlier eras of technological innovation. They have great potential for addressing existing needs, increasing productivity and improving livelihoods, and can play an essential part in development.[2]

Nevertheless, while offering distinctive opportunities, fresh waves of technological change also create new kinds of problem. One risk is that frontier technologies could disrupt labour markets. A standard view has been that innovations in processes increase productivity and thus destroy jobs, while innovations in products generate new markets and thus create jobs. There is also the possibility that frontier technologies could reduce the labour component of production, so reducing the incentive for developed countries to move labour-intensive work to less industrialized economies. In China, for example, this could delay or slow the shift of more traditional industries such as garments, footwear, and low-tech electronics to less-industrialized countries in Asia and Africa.

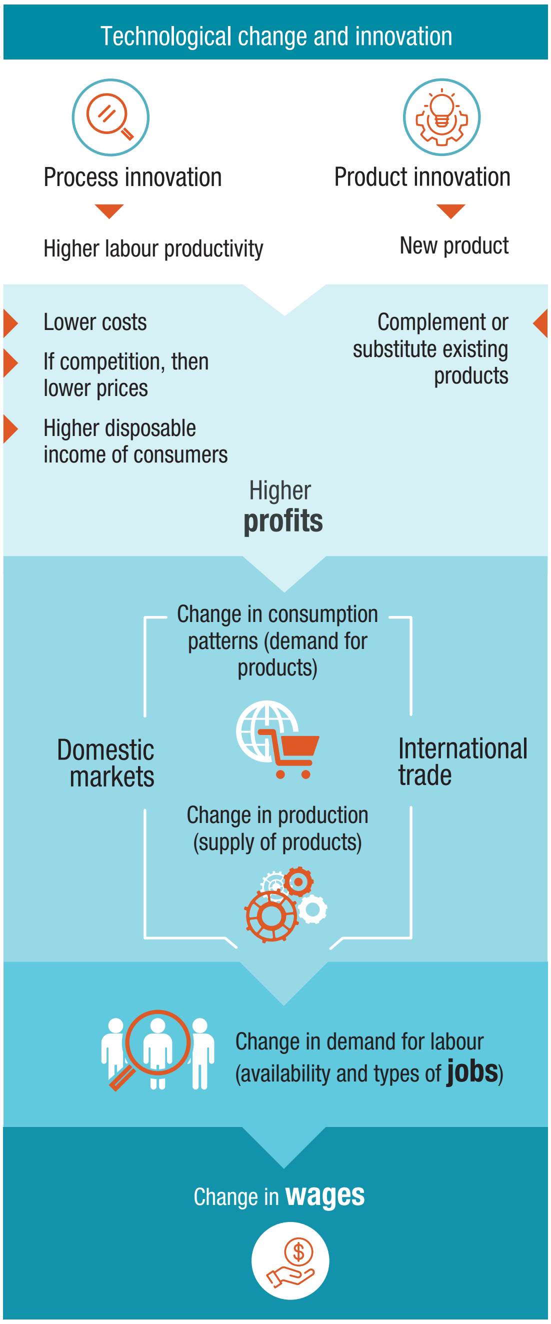
Moreover, while frontier technologies offer a window of opportunity for developing countries to accelerate economic growth, they could also widen technological gaps between countries, making it even more difficult for less-industrialized countries to catch up , diversify their economies and create more jobs. Much will depend, however, on the array of industries a country can grow or attract, which in turn depends on its strategic promotion of new sectors, investments in people and infrastructure, as well as on its business and regulatory environments.

A. TECHNOLOGIES AFFECTING INEQUALITY THROUGH JOBS, WAGES AND PROFITS

Frontier and other technologies can change how people work and produce goods and services, thus changing how wealth is created and distributed. In long chain reactions through an economy, technological change creates, destroys and transforms jobs – producing winners and losers. International trade can then transmit these impacts between countries.[3] Technological change also affects wages and profits, which in turn widens gaps within and between wage earners and the owners of capital (Figure III 1).

The resulting income inequality between people can be seen as a composite of various

Figure III 1
Innovation affects profits, jobs and wages



Source: UNCTAD.

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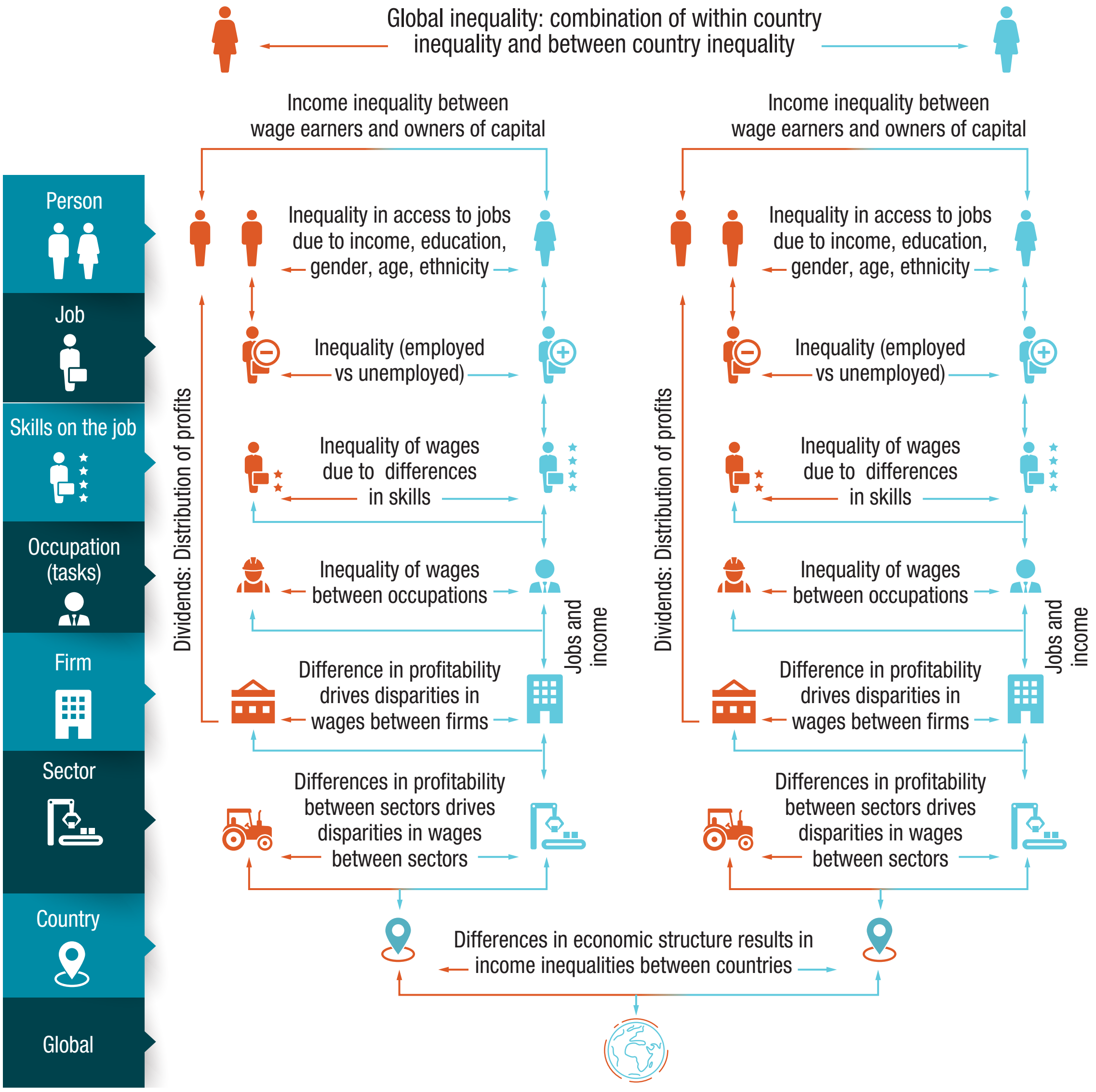
disparities – as illustrated in Figure III 2. Gaps open up between the unemployed and the employed, and also between workers due to differences in skills[4] and occupations,[5] as well as between firms,[6] and sectors.[7] At the international level, inequalities can arise due to differences in economic structures – on how each sector contributes to employment and productive capacity and thus to average productivity and income.

Income inequalities also emerge between wage earners and the owners of capital. As well as paying wages, firms distribute profits to investors through dividends and in some cases remunerate white-collar workers with equity. However, much depends on the prevailing social and economic frameworks – how different groups in society negotiate divisions of power, and what levels of inequality they will tolerate. Inequality of all forms is always shifting as a result of a multitude of factors of which technological change is only one.

Sweden, for example, has collective wage agreements that reduce the scope for variations in wages between firms.[8] The United States, on the other hand, has less collective bargaining and

Figure III 2
A chain reaction of inequalities



Source: UNCTAD.

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Table III 1
Top computer services, software and office equipment companies, 1995–2020

	1995	2000	2010	2020
1	International Business Machines Corporation	International Business Machines Corporation	Hewlett-Packard Company	Apple
2	Fujitsu Limited	Hewlett-Packard Company	Microsoft Corporation	Microsoft
3	Hewlett-Packard Company	Fujitsu Limited	Dell Inc.	Dell Technologies
4	Canon Inc.	Compaq Computer Corporation	Fujitsu Limited	HP
5	Digital Equipment Corporation	Dell Computer Corporation	NEC Corporation	Lenovo Group

Source: UNCTAD based on data from Global 500 (2020).
Note: Companies are ranked by revenue.

between 1978 and 2013 an estimated two-thirds of the rise in the earnings disparity was due to differences between firms.[9] In Brazil between 1996 and 2012, inequality fell partly due to a levelling off of productivity between firms.[10]

Disparities in income are not inherently harmful.[11] Some differential in wages helps reallocate talent to more productive activities.[12 13] Similarly, if entrepreneurs see the prospect of higher profits they have an incentive to innovate.[14] And since most of the social returns of innovation are captured by consumers (through new and improved products, more choices, and lower prices), society as a whole should be better off. Moreover, some of these disparities may only be temporary – particularly those between firms.[15] For example, the computer services, software and office equipment industry between 1995 and 2019 saw major changes in company rankings driven mainly by innovation (Table III 1).

Disparities in income also reflect forms of discrimination in society of which one of the most important is gender. Women and girls are less likely to use the Internet and they are also underrepresented in STEM fields. They tend not to work in ICT specialist occupations and are found more in low-growth occupations such as sales or clerical work – resulting in persistent gender pay gaps.[16] These and many other disparities such as those associated with ethnic origin can become connected and entrenched.[17]

Innovation will thus have an impact on jobs, wages and profits but its magnitude and stickiness will depend on many factors – productive structure, demographic makeup, levels of development and social and economic policies.

B. RISKS OF UNEMPLOYMENT AND INCREASING INCOME DIVIDES

How do frontier technologies make the processes described above different from the past? In principle, there is no difference. Similar disparities have occurred before. Each technological revolution had its winners and losers requiring societies to create new institutions to spread wealth more evenly and re-establish social cohesion.[18] However, each wave of technological change creates different forms of inequality, and distinct problems which policy makers and institutions need to solve to ensure sustainable outcomes.

Nowadays one of the major concerns is the impact on labour markets of AI and robotics combined with big data and IoT.[19] In particular there are fears that these technologies will replace middle-skill jobs and encourage the growth of the gig economy which is associated with low wages and job insecurity. They could also widen disparities between companies and sectors by concentrating the profits from these technologies in a few dominant companies. A concern for developing countries is the risk of widening technological gaps between countries and a rise in global inequality.

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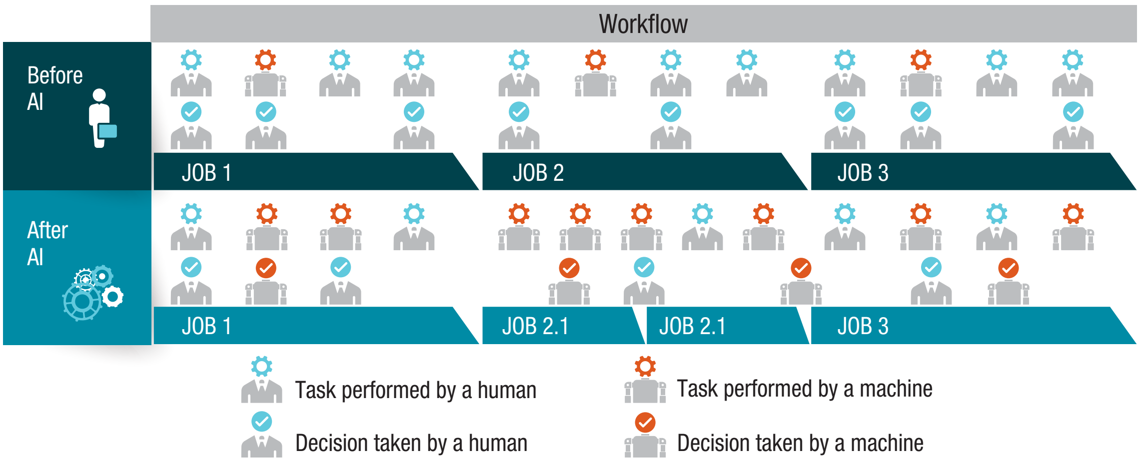
1. AUTOMATION TAKING JOBS

Since the onset of the industrial revolution workers have expected new technologies to destroy jobs.[20] In the past this has generally not happened; new technology has instead tended to create many more jobs, and of different kinds.[21] But some people believe that the situation could be different for frontier technologies because the changes are so fast that they could outpace the capacity of societies to respond.[22]

Previously, many jobs were considered safe because it was difficult to teach computers how to perform them. Now, through machine learning, computers can teach themselves how to complete some tasks.[23] AI can also use modelling and a lot of data to make predictions that mimic human intelligence.[24] This alters the nature of jobs by increasing or reducing the number of tasks. Some jobs will disappear, but others will emerge – such as those requiring empathy, inventiveness and ethical judgements that need to be made by humans.

This is illustrated schematically in Figure III 3 which shows a hypothetical workflow for three jobs in which tasks are performed in sequence; those by humans in blue, those by machines in grey. Tasks that require decisions are associated with human intelligence – such as making predictions based on data and previous knowledge. Before AI, these decisions were difficult to automate. In this case, after AI the number of jobs increases but with a different distribution of tasks.

Figure III 3
Jobs, tasks, decisions and automation by AI



Source: UNCTAD based on Agrawal et al. (2018) and Acemoglu and Restrepo (2019).

There is considerable debate regarding the pace and impact of technological change (see Box III 1). Some analysts warn of imminent widespread disruption of labour markets – and even threats to human existence.[25] More conservative studies, usually from experts in specific technologies, are cautious of overestimating effects in the short term and underestimating those in the long term.[26]

Box III 1
The Future Will Not Take Care of Itself[*]

The industrialized world is undergoing rapid employment growth. A May 2019 cover story in The Economist magazine declared that "most of the rich world is enjoying a jobs boom of unprecedented scope."[27]

Nonetheless people throughout the industrialized world are pessimistic about the future of work. In 2018, the Pew Research Center found that between 65 and 90 percent of those surveyed in advanced economies believe that robots and computers will probably or definitely take over many jobs now done by humans.[28]

The possibility that machines may eliminate jobs is not bad news if these technologies deliver higher living standards. But the Pew survey makes clear that citizens do not expect to benefit: most people believe that

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automation will exacerbate inequality between rich and poor while making jobs harder to find. Less than one third of those surveyed believe that new, better-paying jobs will emerge.

Why, after a decade of rising employment, are people pessimistic about job prospects? One possibility is that the avalanche of alarmist "end of work" newspaper articles, books, and expert reports have overwhelmed the facts. Perhaps, in the words of the Economist, "the zeitgeist has lost touch with the data."

Alternatively, public pessimism may reflect the hard-learned lessons of recent history. Citizens may worry that the introduction of new technologies with human-like capabilities will generate enormous wealth for a minority while diminishing opportunity, upward mobility, and shared prosperity for the rest of us.

Economic history confirms that this sentiment is neither ill-informed nor misguided. There is ample reason for concern about whether technological advances will improve or erode employment and earnings prospects for the bulk of the workforce. The last four decades of economic history in industrialized countries reveals a startling disconnect between rising productivity and stagnant incomes for large fractions of the workforce. The challenge is not too few jobs. Instead, it is the quality and accessibility of the jobs that will exist and the career trajectories that they offer to workers, particularly to those with less education.

New and emerging technologies will raise aggregate economic output and boost the wealth of nations. Accordingly, they offer the potential for citizens to realize higher living standards, better working conditions, greater economic security, and improved health and longevity.

But whether nations and their populations realize this potential depends on the institutions of governance, societal investment, education, law, and public and private leadership to transform aggregate wealth into greater shared prosperity instead of rising inequality. By enacting far-sighted policies to invest in their citizens, protect and augment workers, and shape not just the speed but also the direction of innovation, nations can cultivate this historic opportunity to generate broadly shared prosperity. These opportunities are within our grasp, but they are far from inevitable. The future will not take care of itself.

[*] *The views expressed herein are those of the author and do not necessarily reflect those of the United Nations or its officials or Member States*

Source: Contribution by David Autor (MIT Department of Economics).

Most assessments of the impact of AI and automation on jobs have focused on more advanced economies. Some estimates suggest that over the next 20 years, in Europe and the United States 30 to 50 per cent of jobs could be automated (Table III 2).[29] Others see a more modest impact – from 8 to 14 per cent across occupations.[30] Moreover, because of the uneven gender balance for occupations, women and men will be affected differently.[31]

Table III 2

Estimated impact of AI and robotics on jobs

	Time frame	Source
47 per cent of total United States employment at high risk of being automated	10–20 years	Frey and Osborne, 2017
9 per cent of total employment in the United States and 21 OECD countries at high risk of being automated	10–20 years	Arntz et al., 2017
50 per cent of today's work activities worldwide could be automated	By 2055	Mckinsey Global Institute, 2017
14 per cent of jobs for 32 OECD countries are highly automatable with a probability of automation of over 70 per cent, while another 32 per cent of jobs have a risk of between 50 per cent and 70 per cent	10–20 years	Nedelkoska and Quintini, 2018
14 per cent of EU jobs face a very high risk of automation	10–20 years	Pouliakas, 2018
30 per cent of jobs are at risk of automation, and 44 per cent of jobs of workers with low education are at risk of automation	Three waves: early and late 2020s, and mid-2030s	PwC, 2018
8.5 per cent of the global manufacturing workforce, mostly in lower-income regions of major economies, could become redundant due to industrial robots	20 years	Oxford Economics, 2019

Source: UNCTAD's compilation.

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The large differences in estimates reflect different methodologies and assumptions. Some studies overstate the impact by assuming the automation not just of specific tasks but entire occupations.[32] This distinction between occupations and tasks is critical since even occupations at high risk of automation can perform tasks that are hard to automate.

> More conservative studies, usually from experts in specific technologies, are cautious of overestimating effects in the short term and underestimating those in the long term.

Other studies focus on tasks.[33] They try to identify those that are automatable and then assess what proportions of the current jobs are composed of these tasks. A problem of this approach is that it is difficult to estimate how AI will develop in future and which tasks it will be able to replace. For example, in the early 2000s it was thought that driving a car would be too difficult for AI;[34] now, AI is aiming for "driverless" cars.

Another challenge with this task-centred approach is that it does not account for workers adjusting by taking on new tasks complementary to the new technologies. As a result, the content of an occupation will change over time even if its name stays the same. Thus, a journalist is now expected not just to collect the information but also enter it into the publication's computer system taking over some of the tasks formerly done by a compositor.

However, the main problem with both occupation- and task-based predictions is that they are based solely on technological feasibility. They may not consider economic factors – such as how demand for jobs will change due to technological advances and the fact that the economy will create entirely new occupations. Much depends on relative prices; capital may not replace labour even when it is technologically feasible, while other macroeconomic effects could increase overall labour demand.[35] Nor do such predictions consider the social acceptance of automation. For example, some of a nurse's work may be susceptible to automation, but this option may be rejected because an important benefit of hospital treatment is human interaction.

Another approach is to assess the potential impact of AI on jobs by using economic models.[36] Instead of predicting the number of jobs that could disappear, they seek to understand the channels of impact of automation on jobs and tasks and the effects of the demand for skills. However, their application for developing countries is limited because they do not consider the potential impact of AI and robots on employment through changes in trade patterns.[37]

The *Technology and Innovation Report 2018*, concluded: "the impact of automation is likely to depend less on its technological feasibility than on its economic feasibility".[38] Recently, commentators have moved from doomsday scenarios to a more optimistic forecasts,[39] although pessimistic outlooks are still common.[40]

Another concern for developing countries is that MNEs could take advantage of AI, robots and 3D printing, to reshore production back to developed countries. A study in Sweden found that one of the stronger drives for reshoring for Swedish manufacturing companies was the increased degree of automation.[41] But the feasibility of reshoring depends on many other factors, including ownership, and the scale of production, and its position in the supply chain. For the apparel and footwear industries, for example, it may be more useful to keep production close to the sources of materials. A recent study found that the risk of job displacement and reshoring were exaggerated for apparel, given the realities of the factory floor.[42] It may also make less sense to reshore from developing countries that have growing populations and expanding middle classes that offer growing markets.

2. JOB POLARIZATION

Job polarization refers to an expansion in high- and low-wage jobs combined with a contraction in middle-wage jobs. This phenomenon is not new; it has been documented in many advanced economies since the 1970s,[43] though it is not yet happening to any great extent in developing countries.[44 45]

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Polarization has intensified in developed countries as skilled cognitive tasks are increasingly supported by computers. Higher-paid occupations tend to benefit more because they use computers more intensively than lower-paid ones.[46] These occupations steadily absorb tasks from other professions; for instance, when a manager starts to book her own travel instead of relying on an assistant.

Computerization reduces the demand for middle-wage jobs, such as those of clerks doing routine tasks.[47] Thus far, there has been less impact on the demand for many of the lowest-skilled manual tasks, but that seems set to change with greater use of AI and robots.[48] A study based on data on robot adoption within industries in 17 countries found that increased robot use reduced the share of employment of low-skilled workers.[49] In addition, ever-more-capable robots and AI software will put further pressure on workers performing routine tasks, both manual and cognitive – from strawberry pickers to radiologists.[50]

AI can also affect the quality of employment – making it more interesting for high-skilled workers, but more boring for low-skilled workers. AI systems can also make high-skill jobs more problem-solving and demanding. In contrast, low-skilled workers are more likely to be receiving orders or instructions automatically generated by an AI system.[51] A recent survey examined differences in the use of AI by workers in Denmark and found that high-skilled workers tended to use information compiled automatically by the AI systems for making decisions or advising clients (Box III 2).

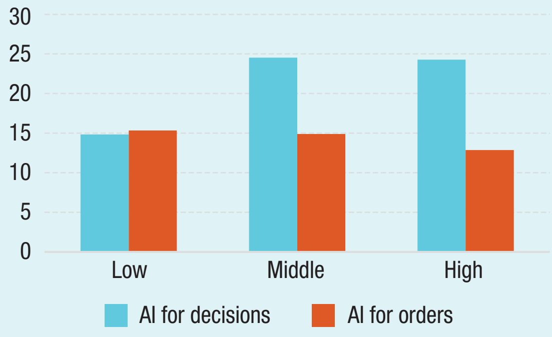
Box III 2

Artificial intelligence, work organization and skills in Denmark

One of the world's first surveys of employees' use of AI on job and skills was conducted in 2019 by IKE, Aalborg University Business School, Denmark. This distinguished two uses of AI. The first is where the employee uses information compiled by the AI system to help them make decisions or advise clients. This corresponds to the idea that AI systems may enhance the skills of employees by providing useful inputs for further decision-making. The second is where the employee merely receives orders or instructions generated automatically by the AI system.

The survey found that around one-quarter of all employees used AI in one or other of the two forms at least once a month. However. the high-skilled workers were more likely to use the first form. As indicated in the figure below, while a similar proportion of all three categories of worker used AI to receive orders, a much higher proportion of the middle and high-skilled workers used it to support decision making.

Share of employees using AI by type of use



The study also found that using AI for decision making increased the complexity of problem-solving tasks and thus made the work more demanding and interesting, while just receiving AI-generated instructions tends to make work more repetitive. The study shows the importance in both developed and developing countries of reshaping education and training system to best prepare students for working life.

Source: UNCTAD based on Gjerding AN, Holm JR and Lorenz E and Stamhus, J (2020). Ready, but challenged: Diffusion and use of artificial intelligence and robotics in Danish firms: Findings from the TASK survey. Alborg University Business School working paper series 001-2020.

Not all job polarization can be attributed to technological change. In advanced economies job polarization has been taking place during a period of globalization – and the shift in employment from manufacturing to services (Figure III 4).[52] In Sweden, for example, the 1970s and 1980s

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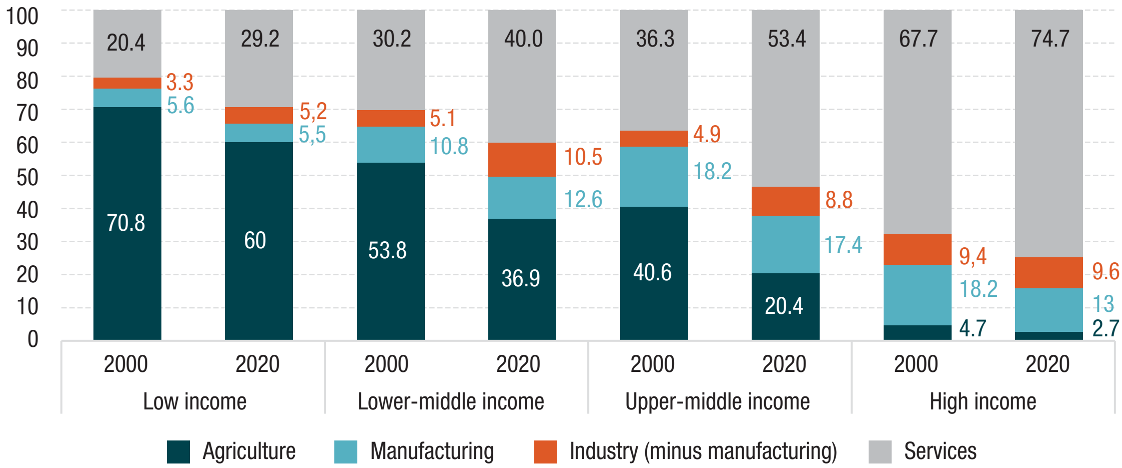
Figure III 4

Employment by broad economic sector, income grouping
(Percentage of total employment)



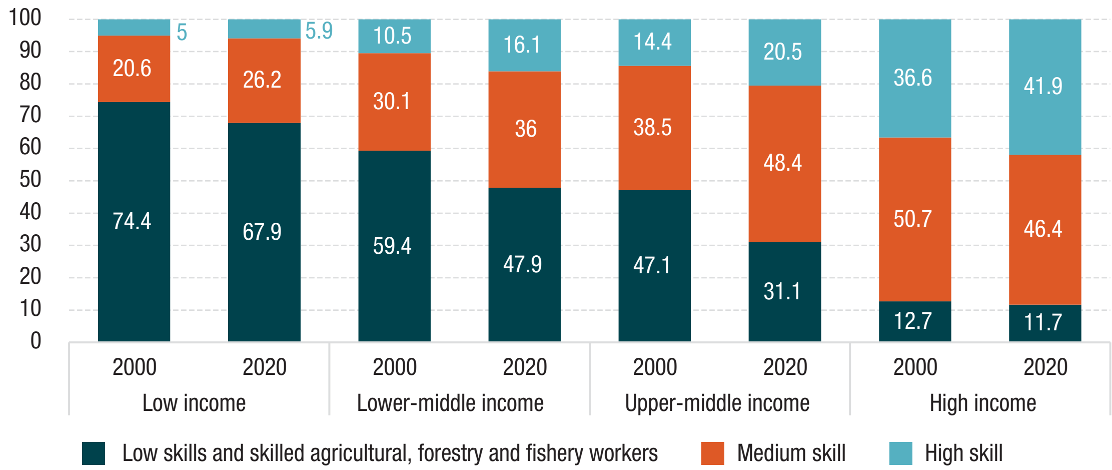
Source: UNCTAD based on data from ILOStat.

were periods of pronounced job polarization, but one study concluded that this was not due to routine-based technological change.[53] For the low- and lower-middle-income countries the greatest shift in employment has been from agriculture to services.

Over the same period, there has been a trend towards higher-skill employment (Figure III 5). In upper-middle- and high-income countries, most work is in middle-skill jobs – such as clerical support workers, service and sales workers, craft and related trades workers, plant and machine operators, and assemblers. In the high-income countries there was a significant share of high-skill jobs. All country groupings, however, saw an expansion of high-skill occupations. Only the high-income countries had a reduction for medium-skilled workers.

Figure III 5

Employment by skill level
(Percentage of total civil employment)



Source: UNCTAD based on data from ILOStat according to the ISCO-08.
Notes: Following ISCO-08 construction logic, a high skill level refers to major groups 1 to 3, a medium skill level to major groups 4, 5, 7 and 8, and a low skill level to major group 9 (skilled agricultural, forestry and fishery workers correspond to group 6, which is also considered medium skill but is combined with group 9 in the data made available by ILOStat).[54]

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Some of the job polarization over this period will have been caused by automation, but much will also have been the result of trade and international competition. A study of job polarization in Denmark between 1999 and 2009 suggested that the main cause was import competition, through worker-level adjustments – with the highly educated and skilled workers ending up in high-wage jobs whereas less-educated workers ended up in low-wage positions.[55] The workers most affected were those doing manual tasks regardless of how routine they were.

Another study, in Germany, found that the decline in manufacturing employment was steeper in import-competing than export-oriented sectors.[56] However, the authors found that manufacturing jobs were retained because of rising trade with China and Eastern Europe. Moreover, the increase in services was caused by people entering the labour market, either young people or those returning from non-employment.

Adjustment in local labour markets due to import competition can be slow. A study on the effects of China's emergence as an industrial powerhouse in local labour markets in the United States found that in the cities more affected, wages and labour-force participation rates sometimes remained low, and unemployment rates remained high, more than a decade after the start of the China trade shock.[57]

Technological change is thus interlinked with structural changes and international trade. Low and middle-income countries are probably less exposed to potential negative effects of frontier technologies such as AI and robots on job polarization.

3. THE GIG ECONOMY AND AN EROSION OF LABOUR RIGHTS

Frontier technologies are being used to provide services via digital platforms that have spurred the creation of a 'gig economy'.[58] Some of this gig work is location-based, as for example, provided by Uber and Airbnb.[59] But it also includes "cloud work", tasks that can be performed anywhere via the Internet, such as through Amazon Mechanical Turk and CrowdFlower. The latter can include captioning images and cleaning data that can then be used by AI algorithms.[60] There are thus opportunities for people in many developing countries to earn incomes, while also developing new skills and joining professional networks.

While the gig economy provides work, this is typically on insecure terms, creating a precarious class of dependent contractors and on-demand workers.[61] These workers generally have fewer labour rights and less negotiating power than waged-employees and can be underpaid with little social protection.[62] This employment also competes with more secure traditional occupations such as taxi drivers and hotel workers.[63]

It is less clear what impact the gig economy will have on income inequality. Much will depend on whether the gig workers are poor people who would otherwise be unemployed, or middle-class people looking for a small additional income. Inequality will also rise if these jobs replace better-paid ones or full-time jobs with part-time ones, or if profits grow faster than salaries.

If service occupations are tradable in the global labour market, these salaries may converge. This has happened in computer coding, for example, and digital design as well as in medical diagnostics, paralegal assessments, and image recognition. Anyone with access to the Internet and the right skills can join a global labour market. But at the national level the impact on inequalities is more ambiguous because the tradable work is usually for low- or middle-income occupations. The people earning the most such as bankers, lawyers, and doctors are likely to be protected by market regulation, or in the case of business executives and performers because they are already operating in a global market for talent.

The gig economy may also increase gender inequality. An ILO survey on digital platforms shows that, on average, women represent only one in three workers; and in developing countries only one in five workers.[64] Another study found that, although women work on the platforms for more hours than men, they earned only about two-thirds of men's rates.[65]

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4. MARKET AND PROFIT CONCENTRATION

These new digital platforms benefit from network effects so markets tend to concentrate, leaving a small number of very large players, as illustrated in Table II 3.[66] This could increase inequalities within sectors, between firms, and between capital and labour. With fewer competitors there is less incentive to reduce prices – and higher profits can widen inequality between wage earners and the owners of capital. And for some IT skills these companies may become almost the only employers – a “monopsony”.

With few companies there is also the temptation for tacit collusion.[67] This may happen unintentionally given the extent of B2B data exchange through algorithms. This is a new area of research with many unanswered questions.[68] Some researchers argue that algorithmic collusion is more difficult to achieve than legal scholars have assumed.[69]

Competition policies will need to be updated – and broadened to consider issues such as consumer privacy, personal data protection, consumer choice, market structure, switching costs and lock-in effects.[70] UNCTAD’s Digital Economy Report 2019 provides an in-depth analysis of the impact of digitalization and the market concentration of global digital platforms, and presents an extensive discussion of the regulatory issues and new challenges for competition and consumer protection policies.[71]

5. AI AND GLOBAL ECONOMIC INEQUALITIES: THREE PROBABLE SCENARIOS

Some estimates suggest that by 2030 AI will contribute an additional $15.7 trillion to the global economy – of which 40 per cent will come from productivity gains and $9.1 trillion from consumption side effects.[72] This would be a consequence of government-led advances in China and corporate-led advances in the United States.[73] Although competing for global dominance in AI, both countries now have digital platforms that gather massive amounts of data from global user bases. Of the total, China would take $7 trillion and North America $3.7 trillion. On this scenario, these countries would leave the rest of the advanced industrialized economies behind.[74] A new ‘great divergence’ would thus be driven not by manufacturing but by user-generated data.

In a second scenario, the main source of big data used by AI would not be human beings but the internet of things (IoT). The IoT consists of machines talking to each other and finding new ways of producing goods. This new wave of active AI will use incoming data to produce better machines and final goods. If so, this would benefit the countries manufacturing those things – such as members of the EU, Japan and the Republic of Korea. They could keep up with the United States and China while pulling ahead of countries that have lower levels of AI automation or manufacturing. In an IoT scenario, manufacturing is still the basis for competitive advantage among countries. As discussed in Chapter I, this represents a continuance of the great divergence from 1820 to 1990, where West European economies and their offshoots forged ahead by increasing productivity in manufacturing.[75] This would thus accentuate an existing global divide rather than creating a new data-driven one.

A third scenario involves equipping machines with conceptual frameworks of how the world works – allowing them to learn more like humans by recognizing patterns and generalizing from a few examples.[76] This method of mimicking human intelligence harks back to the origins of AI. In recent years this top-down method appeared to have been set aside in favour of bottom-up, data-driven methods. The latter have several disadvantages. One is the problem of “edge” cases for which the machines have insufficient data – as when self-driving cars encounter real-life scenarios that were not part of their massive training datasets. Also, if something goes wrong it can be impossible to work out how a data-driven system arrived at a decision. There may also be ethical obstacles if governments are concerned about their citizens’ privacy and limit the collection of training data.

In recent years new research and computational tools have revived the original prospect of equipping machines with human-like reasoning capabilities. This typically involves probabilistic models that

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can deal with extensive uncertainty, work with limited data, and learn from experience. Such models could be used anywhere, so would not particularly benefit the United States or China, but they would still require the kind of resources and capabilities more likely to be found in the developed countries, which could thus pull further ahead of the developing countries.

6. WIDENING TECHNOLOGICAL GAPS

Extensive adoption of frontier technologies could enable developed countries to pull further ahead of less- industrialized economies. A widening technological gap would make it more difficult for these less-industrialized countries to catch up, diversify their economies, and create jobs. The alternative is for the developing countries themselves to scale up the deployment of these technologies – a daunting, but achievable, task.

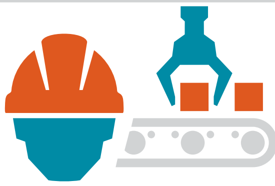
In the past, countries like China, Mexico, Brazil, and a handful of Asian economies moved up the income ladder by transferring labour and capital from lower-productivity agriculture to higher-productivity manufacturing and services. Within manufacturing, following the "flying geese" model these countries built capacity and skills, moving up the value chains, replacing low-wage, low-skill manufacturing activities with higher-skill, higher-value added production.[77] Meanwhile, recent newcomers to the development process picked up the low-skill activities that the more advanced developing countries had outgrown.

The fear now is that frontier technologies and Industry 4.0 will upend these traditional development processes, making a difficult journey even harder. While it is important to address these fears, the dangers need to be put in context. LDCs and low-income countries may not be affected if they do not have the low-wage assembly jobs that are in greatest danger of being destroyed by frontier technologies.[78] At the same time, there may be areas where low-income countries can benefit directly from frontier technologies.

C. CHALLENGES FOR DEVELOPING COUNTRIES

The likely impact of rapid technological change on inequality is thus uncertain. The actual effect will vary from sector to sector and depend on the capacities of countries, as well as on their policies and strategies. Some workers will lose their jobs and have to find other occupations, and there will be consistently fewer jobs in certain occupations and more in others. Some workers should be able to adapt through retraining or switching careers. But change may also be faster than people's ability to adapt; some may never be able to do so. Therefore, all governments should aim to see frontier technologies disseminated through production structures while devising ways to mitigate adverse effects.

GOVERNMENTS SHOULD AIM TO SEE FRONTIER TECHNOLOGIES DISSEMINATED THROUGH PRODUCTION STRUCTURES WHILE DEVISING WAYS TO MITIGATE ADVERSE EFFECTS



Developing countries can use automation to increase productivity and wages while also promoting economic diversification that will create jobs. Nevertheless, in pursuing these policy objectives, developing countries face several challenges, including demographic change and the lack of capacity, and a shortage of finance. They could also be obstructed by more stringent protection of intellectual property.

1. DEMOGRAPHIC CHANGES

World population is expected to increase from about 7.9 billion people in 2020 to 9.7 billion by 2050. As shown in Figure III 6, The most significant increases will be in low and lower-middle-income

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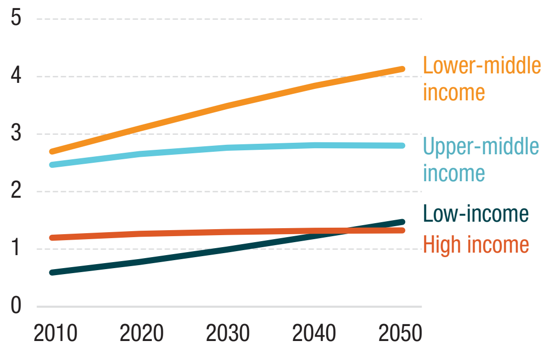
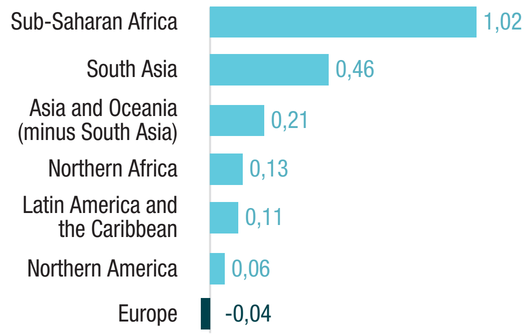
Figure III 6
Population, by country income group, billions



Source: UNCTADStat.

Figure III 7
Change in population between 2020 and 2050, billions



Source: UNCTADStat.

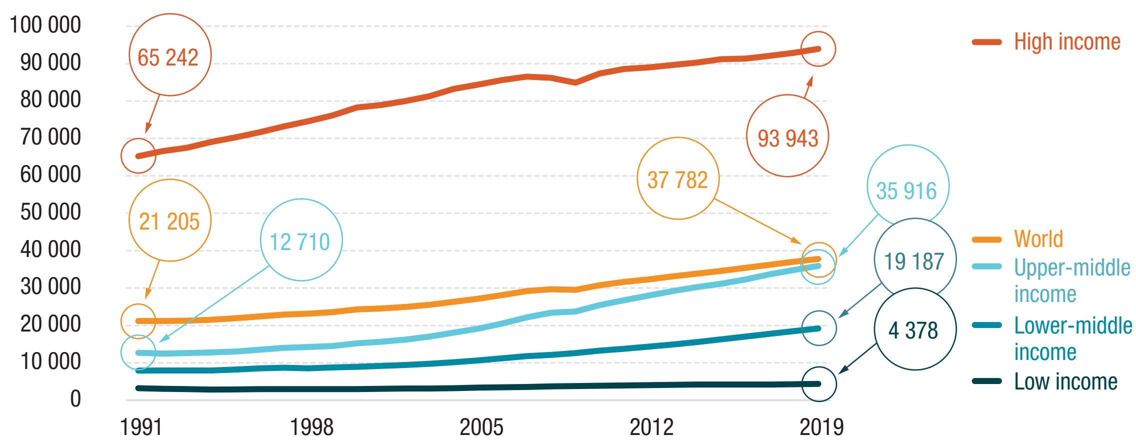
countries, while the population in high-income countries is likely to remain stable. Between 2020 and 2050, most of the increase in population will be in sub-Saharan Africa, by more than one billion, and in South Asia by almost half a billion (Figure III 7). Expanding and younger populations will increase the supply of labour and depress wages, reducing the incentives for automation.

The actual process will vary between firms and industries and depend to some extent on government policies.[79] In India, for example, despite a large labour surplus, firms that have easier access to foreign technology and imported capital have adopted advanced manufacturing techniques.[80] In other regions with falling populations, or slower increases, automation will not lead to mass unemployment.

2. LOWER TECHNOLOGICAL AND INNOVATION CAPACITIES

Adopting new technologies should increase productivity. Between 1991 and 2019 average output per worker increased steadily (Figure III 8). Globally the increase was from $21,205 to $37,782 per worker. In absolute terms, the biggest increase was in the developed countries, but in relative terms, the most significant increase was in upper-middle-income countries, from $12,710 to $35,916. There was also a substantial increase in lower-middle-income countries, but very little progress in low-income countries so the gap between these and other country groupings widened. This is partly because the poorest countries depend to a large extent on agriculture which offers less scope than manufacturing for

Figure III 8
Output per worker, income groupings, $constant international 2011 prices



Source: UNCTAD based on data from ILOStat.

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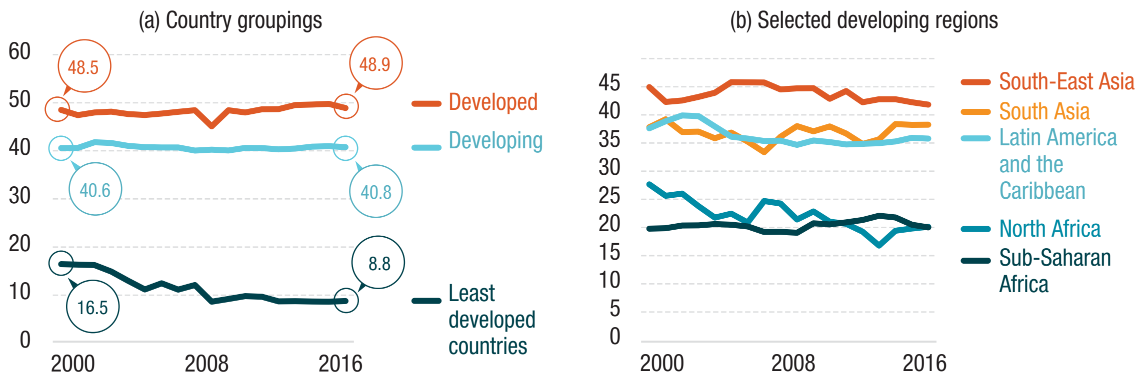
Figure III 9

Proportion of medium and high-tech industry value added in total value added (percentage)



Source: UNCTAD based on data from the United Nations Global SDG Indicators Database.

technological innovation. In developing countries, there are large gaps in productivity between traditional and modern sectors.[81]

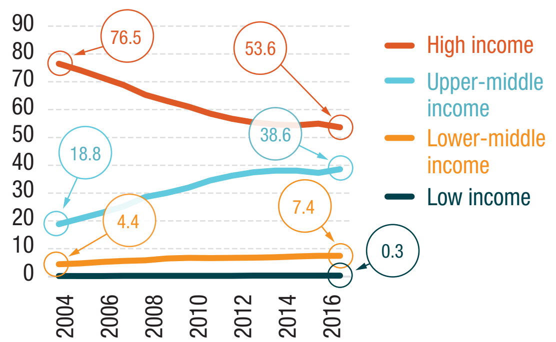
The gap between developed and developing countries can also be seen in their proportions of medium and high-tech value added (Figure III 9 a). Between 2000 and 2016, despite rapid progress in countries such as China, India and Viet Nam, the gap between developed and developing countries remained about the same. Meanwhile, the least developed countries were dropping further behind, with their share falling from 17 to 9 per cent. Among the developing regions, South-East Asia was at the top and sub-Saharan Africa at the bottom (Figure III 9 b).

Most new technologies are likely to be used for manufacturing and financial services in which developing countries in particular LDCs already lag far behind. This is reflected in their low proportions of manufacturing value added (Figure III 10) and in exports of financial services (Figure III 11). High-income and upper-middle-income countries also dominate the automotive and electronics sectors, which between 2005 and 2014 experienced a substantial increase in robot density (Figure III 12).

Developing countries account for a low proportion of scientific research. In 2017, high-income countries had 4,256 researchers per million inhabitants, while lower-middle-income countries had 262 and the low-income countries only 154 (Figure III 13).

Figure III 10

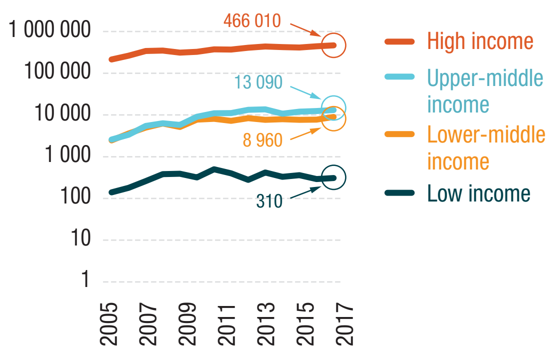
Proportion of manufacturing value added in global manufacturing value-added, country groupings (percentage)



Source: UNCTAD based on data from the World Bank's World Development Indicators.

Figure III 11

Exports of financial services,country groupings ($current prices in millions)



Source: UNCTADStat.

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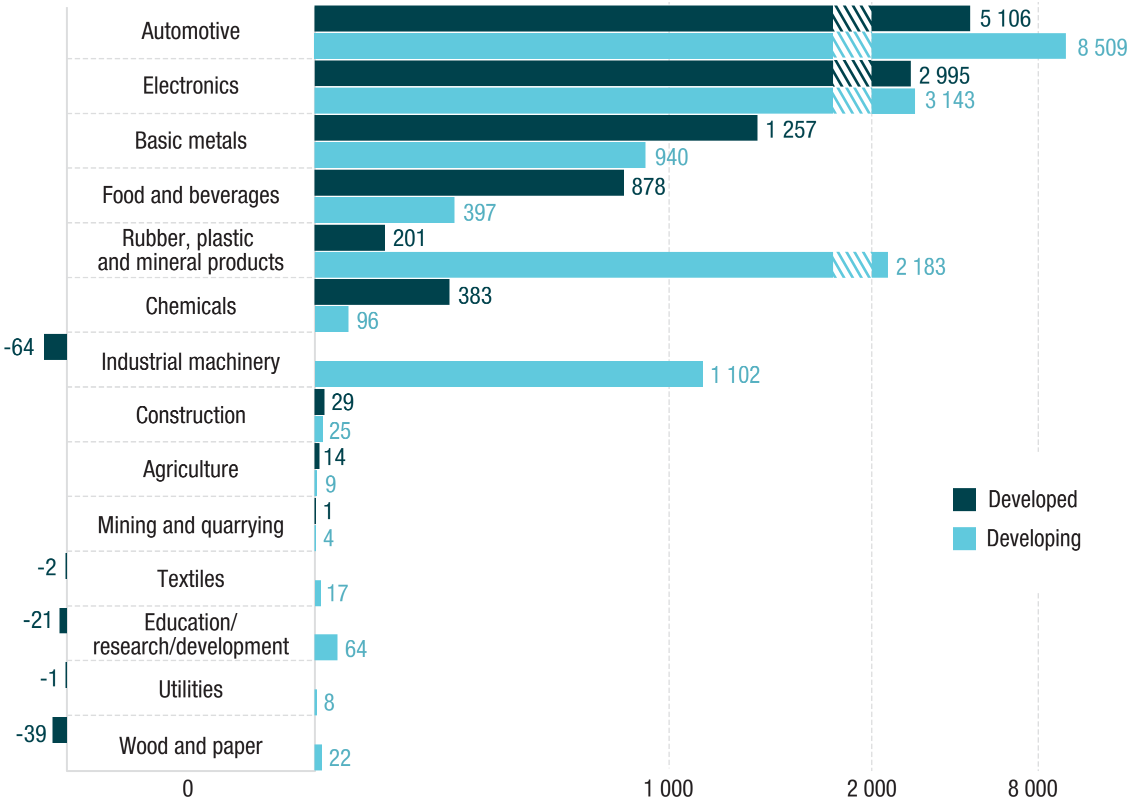
Figure III 12

Change in robot density by industry (per 10,000 workers), 2005-2014



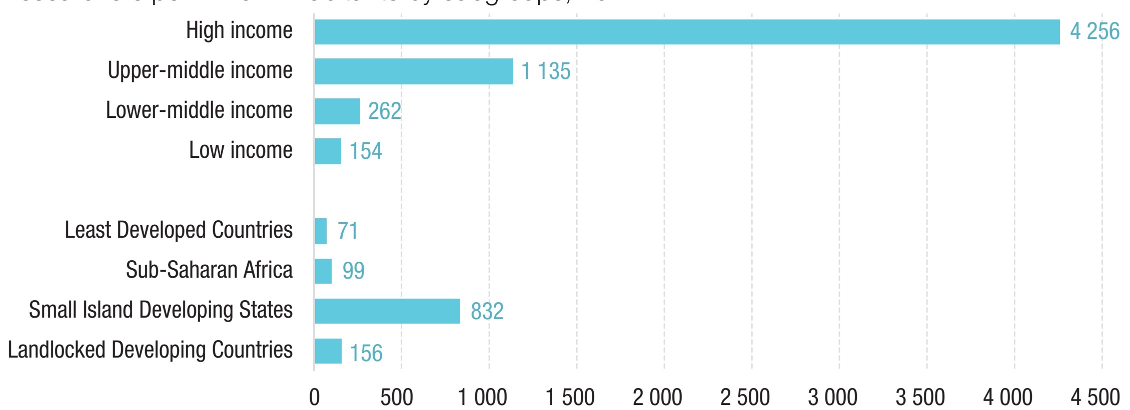
Source: UNCTAD based on data from Carbonero et al. (2018).

Progress in using frontier technologies can also be measured through the number of relevant science and technology publications. Here again, as illustrated in Figure III 14, the developing countries are some way behind. They appear to be keeping pace when it comes to the number of patents, but this is largely due to the contribution from China and India (Figure III 15).

Some technologies, such as 3D printing, offer the prospect of democratizing manufacturing and allowing far smaller production runs. This promise has yet to be realised in developing countries.

Figure III 13

Researchers per million inhabitants by subgroups, 2017



Source: UNCTAD based on UNESCO (2020a).
Note: The country groupings “Least Developed Countries” and “Sub-Saharan Africa” overlap and both contain countries that are also part of “Small Island Developing States” and “Landlocked Developing Countries”.

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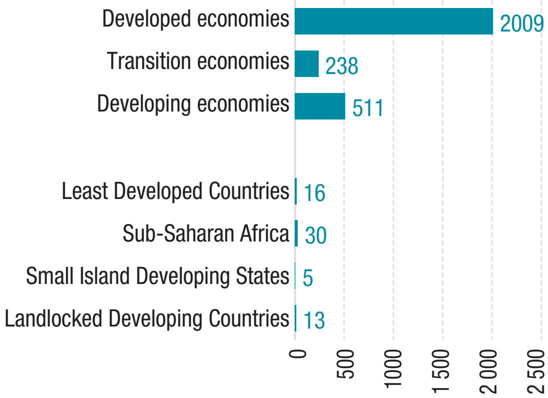
Figure III 14

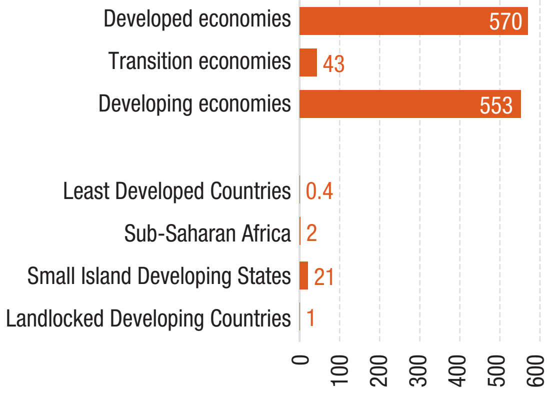
Average number of publications on frontier technologies by subgroups, 2018



Source: SCOPUS. See Annex B for details.

Figure III 15

Average number of patents on frontier technologies by subgroups, 2018



Source: Patseer. See Annex B for details.

The price of equipment did fall after the first wave of patents expired but not far enough for many potential users in developing countries. Even more important, few users in these countries have the skills for producing 3D designs.

The lower technological capacities of developing countries are also seen in the gaps in digital infrastructure and skills, as discussed in Chapter IV.

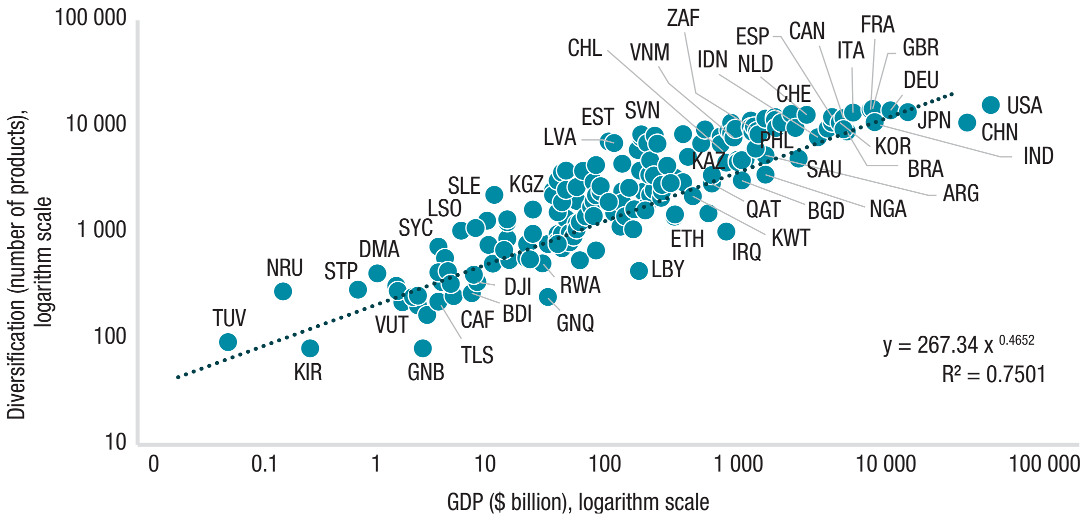
These divides can thus both perpetuate existing inequalities and create new ones. Worst affected are the low-income and least developed countries.

3. SLOW DIVERSIFICATION

If developing countries want to upgrade jobs and production, they will need to move on to more complex goods and services.[82] At present their production systems are far less diverse than those

Figure III 16

Association between total GDP and diversification and complexity of economies, 2019



Source: UNCTAD *based on UN COMTRADE data.*
Note: Based on the number of product categories exported, at the SITC 5-digit level, further disaggregated by unit value using the methodology presented in Freire (2017).

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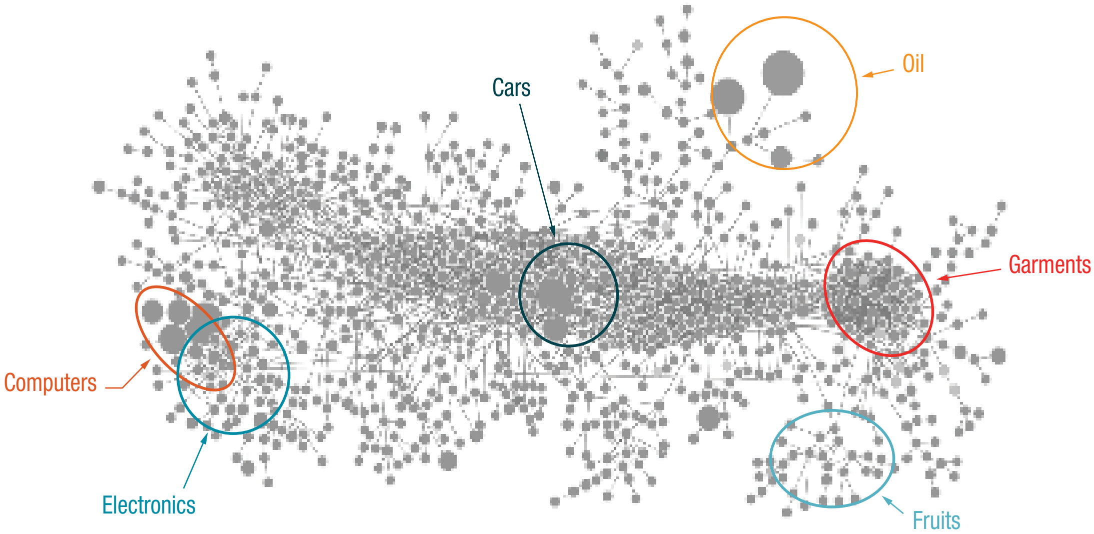
Figure III 17

Products connected to each other based on the likelihood of being exported together, selected clusters of products identified



Source: UNCTAD based on The Atlas of Economic Complexity (2020).
Note: Each dot represents a product using the HS 4-digit data classification. Products that are connected have a higher probability of being exported together. Selected clusters of products are indicated for illustrative purposes.

of developed countries. As illustrated in Figure III 16, generally the diversification of a country's output is associated with its total GDP. When countries develop, they diversify their economies by adding more complex products. These more complex products can be found in any sector – agriculture manufacturing or services – and they do not need to be new to the world, they can just be new to the country.[83] In fact, developing countries typically innovate by emulating industrialized countries, and absorbing and adapting their technologies for local use.[84]

Emulation and diversification tend to be path dependent. What firms in a country produce tomorrow will depend to a large extent on what they produce today; a country will generally emulate in those industries for which it already has some capabilities. This path dependency can be illustrated with product space maps (Figure III 17).[85] The circles represent products which are connected to each other based on how likely they are to be exported together. Some products, such as cars and computers, are more extensively connected than others and offer greater scope for diversification. Others, such as commodities, largely represent dead ends with little scope for moving to other types of production.

The approach will depend on the country's level of economic development and its economic structure, as indicated in Table III 3. Lower-income developing countries should innovate on two fronts. They should adopt and use frontier technologies to improve basic infrastructure, while also investing in late-stage technologies to diversify into more complex products in traditional sectors where they can gain dynamic comparative advantage. High-income countries on the other hand, should promote inclusive and sustainable development of frontier technologies while mitigating the negative impacts of job displacement. Middle-income countries need to pursuit a more of a balancing act, involving innovation in both late-stage and frontier technologies while diversifying their economies.

Developing countries may find it even harder to upgrade because of changes in global production structures. In recent decades, firms in developing countries have been able to enter different, though traditional, sectors by participating in global value chains (GVCs). Now the COVID-19 pandemic has created concerns about the vulnerability of GVCs with potential reduction of cross-border investment.[86] To reduce the risk of disruption firms may shorten their value chains by keeping more production in developed countries (Box III 3). These changes in GVCs would make it more difficult for lower-income developing countries to maintain their production bases and diversify to new sectors.

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Table III 3

Promoting innovation and mitigating the impact of frontier technologies

	Low-income countries	Middle-income countries	High-income countries
Sectors adopting late-stage technologies	Invest in innovation through economic diversification	Invest in innovation through economic diversification, while mitigating the impact of job displacement	Mitigate the impact of job displacement.
Sectors adopting Frontier technologies	Improve the provision of the basic infrastructure (e.g. electricity and ICT) for people and firms and other actors of the NIS to have better access to these new technologies	Promote innovations that apply frontier technologies	Mitigate the impact of job displacement
Sectors developing frontier technologies	Not applicable	Promote further development of frontier technologies	Promote further development of frontier technologies

Source: UNCTAD.

Box III 3

Potential impact of COVID-19 on global value chains

The COVID-19 outbreak delivered both supply and demand shocks to the global economy. Supply was disrupted through lockdowns and production stoppages, logistics disruptions and labour shortages. Demand was reduced through weaker consumption and lower imports. These shocks had adverse effects on production, trade and FDI, and on global value chains (GVCs). UNCTAD projects a decline in global FDI flows of between 5 and 15 per cent in 2020.

The dominant players in GVCs are multinational enterprises (MNEs). To reduce the risk of disruption, MNEs could now shift to more local production – reshoring. This would deprive developing countries of GVC-associated capital flows and access to international markets that can help them build human capital and knowledge.

However, MNEs might find this difficult. Depending on the types of firms, withdrawing entirely from a country could entail more than just relocating manufacture or assembly. They may also have to relocate suppliers, some of whom in turn rely on parts produced by other local companies. In any case, MNEs gain other advantages from GVCs that onshoring cannot offer, such as access to foreign markets.

Instead, they may adjust in other ways. They can, for example, seek ad-hoc assistance from other partner firms in a similar value chain. They may also increase the amount of inventory, and add production lines. To build in more redundancy and make GVCs more resilient may also extend the chains into other countries – offering opportunities to other African, Asian and Latin American countries.

The adjustments to GVCs will depend ultimately on how long the epidemic lasts and how quickly countries can recover – and ultimately on the decisions of individual firms, as seen after Thailand's flood in 2011 when different firms, often in the same industries, responded in different ways.

Source: OECD, 2013; Haraguchi and Lall, 2015; Haren and Simchi-Levi, 2020; Michigan State University, 2020; UNCTAD, 2020a; UNIDO, 2020).

4. WEAK FINANCING MECHANISMS

Another challenge for developing countries is a lack of finance for R&D. Although most developing countries have increased R&D expenditures, these are still relatively small (Table III 4). Some regional organizations have set targets for R&D expenditures, but progress has been slow. For instance, the African Union established a target of one per cent of GDP, but on average sub-Saharan African countries are still at 0.38 per cent.[87] Just as important as the volume of expenditure is its composition. Very little is funded by the private sector – to develop industrial technologies for production.

Table III 4
R&D expenditures by subgroups

	R&D expenditures (average annual growth rate, 2007-2017, percentage)	GDP (average annual growth rate, 2007-2017, percentage)	R&D expenditures as a percentage of GDP, 2017
Landlocked Developing Countries	5.0	5.8	0.21
Small Island Developing States	2.5	0.9	0.96
Sub-Saharan Africa	4.4	4.4	0.38
Least Developed Countries	6.2	5.1	0.20
Low income countries	7.2	4.0	0.29
Lower middle-income countries	4.5	5.5	0.43
Upper middle-income countries	10.2	5.0	1.48
High income countries	2.3	1.4	2.42
World	*4.3*	*2.6*	*1.72*

Source: UNCTAD based on UNCTAD (2020), UNESCO (2020).
Note: The composition of some of the subgroups overlap.

5. INTELLECTUAL PROPERTY RIGHTS AND TECHNOLOGY TRANSFER

A major issue for developing countries is that technologies from developed countries are protected through intellectual property (IP) rights. IP protection can take various forms, including patents, trade secrets, trademarks and copyrights.[88] Without the patent system, there would be little incentive for firms to develop and commercialize innovations. In principle, intellectual property regimes should be geared to each country's needs and capacities, striking an appropriate balance between granting exclusive rights and encouraging follow-on innovation by competitors.

Digital content providers have, however, long been advocating for stronger intellectual property enforcement – for broadening the scope of patents and increasing the duration of copyright works, even though many of these patents remain unused. One practice is to create "patent thickets" by acquiring overlapping patents to cover a wide area of economic activity and downstream inventions. Another is "patent fencing": excessive patenting with the intention of cordoning off areas of future research. Both can extend patent protection over entire technological domains, and guarantee continuing economic advantages to incumbent firms.

Of the various forms of IP, patents are less restrictive than trade secrets since the creator has to disclose the invention – knowledge which can then be disseminated and used as a basis for follow-up innovation.[89]

Stringent intellectual property protection can restrict the use of frontier technologies that could be valuable in various sustainable development areas such as agriculture, health and energy. An algorithm that could be used at almost no marginal cost could still be off limits for many who could benefit from it. Arguably, frontier technology innovations should form part of a new type of technology transfer – covering platform technologies, data collection and mining, processing algorithms and artificial intelligence.[90]

D. ACCELERATING TOWARDS INDUSTRY 4.0

National governments are already addressing the potential negative effects of frontier technologies and have good ideas to share. Many national and local governments are working to stimulate the growth of industries that produce jobs and wealth within their boundaries, which in turn reduces inequalities between countries. National strategies should include:

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1. SETTING STRATEGIC DIRECTIONS

Many countries set their priorities for frontier technologies through national plans for research and innovation. These usually aim to strengthen specific sectors either by encouraging new businesses to form, helping existing businesses to grow, or attracting companies from outside. The plans also identify changes needed in the regulatory environment and the need for investment in physical infrastructure and in training. National plans and strategies can also promote technological applications that could help disadvantaged groups or help stimulate economic development in rural areas or declining regions.

Several countries are using opportunities created by technological advances to take on emerging social challenges:

Ageing – Several national plans mention the ways ageing populations could benefit from the new technologies. Japan's plan points to the issue of ageing and less mobility to which Japan's strong automotive industry can respond, and healthcare which could be supported by robotics. The plan calls for reducing the number of nursing care patients by allowing ageing individuals to remain in the workforce. It also explicitly recognizes gaps in regional economic development and puts forward a long-term vision of revitalizing older urban areas as "smart cities."

> Several countries are using opportunities created by technological advances to take on emerging social challenges

Regional disparities – Many plans address regional disparities. The *EU's* vision for "resilient, sustainable and competitive manufacturing" refers to reducing inequalities between regions.[91] *Mexico's* 2016 Roadmap for Industry 4.0 recommends identifying six states with the potential for implementing Industry 4.0 ecosystems and developing plans for Industry 4.0 clusters there.[92] *South Africa's* Industrial Policy Action Plan for the period 2018–2021 uses Special Economic Zones to work towards regional equalization.[93] Most plans mention the opportunity to spread new manufacturing jobs across unequal regions. Regions can build or rebuild manufacturing capability if they work hand-in-hand with the expertise being developed at the national level.

Diversity – In several cases, issues of diversity get attention, notably in the strategies by *South Africa* and the *United Kingdom*. These issues arise in education, but also in the workforce, and in South Africa in issues of ownership and control. The South African plan mentions the importance of female entrepreneurs. Programmes to develop new skills can operate on a more egalitarian basis and bring in groups that have previously been under-represented.

National plans for STI, in combination with environment and energy policies, enable countries to take advantage of the "green window of opportunity" to promote the technological catch up in renewable technologies (Box III 4).

Box III 4
Green windows of opportunity: latecomer development in the age of transformation towards sustainability

A recent critical examination of the technological catch up in five renewable energies industries (solar PV, biomass, hydro energy, and wind energy) shows that institutional changes are the main drivers for creating new opportunities for latecomer development in the green economy. In particular, new policies and new legislations, related to domestically or global sustainability transformation agendas, are central to latecomer catch up in all sectoral 'take off' cases. Environmental and energy policies are critical for the emergence of Green Windows of Opportunity (GWOs), based on their domestic deployment and market creation effects. At the same time, industrial and innovation policies are also important to promote the firm and system level capabilities to respond to opportunities.

The eventual effects of policy-induced opportunities depend on the actions of firms and other sectoral system public and private actors, as well as on key sectoral characteristics, such as technology maturity and tradability of products and services. Therefore, policies and firm strategies for green latecomer development need to be sector

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specific and a one-size-fits all approach to green energy sectors is not viable. In some cases, the public policy response is concentrated on mission-oriented technological change based on demonstration projects while in other sectors, industrial policy measures such as local content requirements are put in place.

Given the low level of tradability of many products and services in the renewable energy industries, successful latecomer strategies entail the protection of domestic investments. Thus, there is usually significant innovation system openness during the formative phase of sectors, but restrictions are imposed during the scaling up phases.

These findings have important implications for global green transformation policy. Cases of very rapid latecomer catch up in renewable energies suggest that GWOs can be exploited by both developed and developing economies. Countries that take active measures to enhance their technological capabilities and build open national and sectoral innovation systems through trade and investment policies and internationalization of R&D, may achieve faster catch up and, even, leadership. Moreover, the efforts of international organizations, governments and non-governmental organizations across the world, have been effective in promoting institutional change-led, mission-oriented initiatives.

These lessons have valuable policy implications for other sectors, such as public health and digital infrastructure, which are critical for building an inclusive society. Policy coordination and the efforts of the global community in ensuring equal access and responsible provision of global public goods, could create ‘global challenge-led windows of opportunity’.

Source: UNCTAD based on Lema R, Fu X, Rabellotti R (2020). Green windows of opportunity: latecomer development in the age of transformation toward sustainability. Industrial and Corporate Change, 29(5).

There is also considerable room for countries to learn from each other in how to reduce inequalities using opportunities provided by new manufacturing systems. All these projects can help countries become technology leaders.

AI, big data and IoT

Many national innovation strategies have AI, Big Data, and IoT as priority areas. They also appear as part of overall national approaches to the Digital Society, the Information Society, or the Information Economy. While there is a degree of participation in producing these plans, the participants are largely limited to industry, technical experts, and government agencies.

Several countries picture AI as a factor that could greatly improve efficiency in public sector services:

- *Australia* – Expects that AI can help target government services to those that need them most.[94]
- *Italy* – Stresses applications in health and disability as well as learning systems.[95]
- *Japan* – Has established a Strategic Council for AI Technology, in part to assure that appropriate applications are being considered across government agencies.[96] It is aiming for one-stop public services that anyone can access and use at any time.[97]
- *Republic of Korea* – Proposes that new information technologies be applied first in the public sector to solve social problems and thereby help create a market.[98]
- *United Kingdom* – The UK Information Economy Strategy includes improving the delivery of public services.[99]

Some countries promote fronter technologies for regional development:

- *China* – Commits in its “Internet Plus” effort that “In the old industrial bases of the northeast and other parts of China, we will implement policies and measures designed to ensure their full revitalization” and further that: “We will increase support to old revolutionary base areas, areas with concentrations of ethnic minorities, border areas, and areas with relatively high incidences of poverty.”[100]
- *United Kingdom* – The AI strategy for life sciences includes regional foci in Leeds, Sheffield, and Oxfordshire.[101]

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Few national plans refer to the SDGs. India's discussion paper is an exception, addressing global challenges with "moonshot" projects.[102] Several national innovation strategies do point to SDG-related areas, including health and water.[103] But do not refer to the difficulties in implementing new technologies in the least developed environments and describe advances that might just as easily may widen the gaps between rich and poor.

Biotechnology – national programmes

Dozens of countries have reported biotechnology initiatives, and there are also programmes from International organizations including UNESCO, UNIDO and the European Union.[104] These generally address "biotechnology and society". Mostly they focus on safety, risk, and privacy rather the risk of widening inequalities, though some do consider the following issues:

Rural livelihoods – The *Sri Lankan* plan sets, among other broad goals, poverty elimination and reducing income inequalities.[105] The plan points to the possibility of "bio-entrepreneurship" to contribute to livelihoods in rural communities. *India's* Biotechnology Plan also includes specific efforts towards inclusive development.[106] Farmer and community innovation receive attention. Medical innovation should emphasize affordable techniques. A set of societal programmes address women, rural communities, and scheduled castes. Ten per cent of the budget is devoted to development in the underdeveloped Northeast Region. Other plans mention related issues more briefly. The *EU-China* plan for biotechnology cooperation includes urban agriculture, and the European part of the plan refers to rural development.[107] A joint BRICS research programme[108] includes a project on TB drug resistance. The *Canadian* innovation plan from 2014, which includes biotechnology, makes reference to the benefits of innovation for rural and urban poverty, aboriginal groups, and remote communities.[109] The *Czech* plan has biotechnology as a chosen areas of specialization, and shows high awareness of the implications for regional development.[110]

Inequalities between groups – Both *Lithuania*[111] and *Poland*[112] have research programmes targeted at healthy ageing. The *Canada* plan aims most aspects of its human resource development at young Canadians, either in the general workforce in science and engineering.[113] The Canada plan also acknowledges the under-representation of women in the science and engineering workforce. *Norway's* calls for more women scientists and engineers.[114] Initiatives from *Malta* include programmes targeted at female entrepreneurs.[115] The 2019 *Ireland* innovation strategy includes a whole chapter on gender inequalities and women's careers in research.[116]

Biotechnology – International programmes

International programmes are more likely than national programmes to explicitly address inequalities.

Agriculture – There is a strong network of research institutions focused on developing new technologies to help poor farmers. The nodes of the network are the CGIAR centres, and the partners are national agricultural research institutions in dozens of countries of the global South.[117] Active partners in the North often come from agriculture-based universities, such as Michigan State and Wageningen. Over time, the emphasis in the CGIAR centres has shifted from top-down, research-led innovations to deeper consultations with farmers.[118] The gender lens in these consultations is evident. The CGIAR network originally operated in an environment where agricultural knowledge could not become intellectual property but has taken the lead in adjustment to the newer legal regime.[119] Because of strong local connections, the CGIAR centres have been able to introduce some genetically modified crops, with some striking successes such as Nerica rice.

Health – Policies to address inequalities include both "push" (knowledge creation) and "pull" (market incentives). On the push side, resources have grown. For tuberculosis, for example, the top funders in 2017 were in the United States: various institutes at the National Institutes of Health, the Bill & Melinda Gates Foundation, and USAID.[120] Next on the list was UNITAID, a coalition of funders which focuses on medical innovation, followed by Otsuka Pharmaceuticals and the UK Department for International Development. European Union funding has also increased.[121] The emphasis has shifted

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from funding for research in the global North to collaborations and capacity building for research in the global South.[122]

Public-private partnerships – These allow sharing of intellectual property rights which can encourage partners into riskier but important ventures.[123] They have been attracting attention to dengue fever, one of the most neglected tropical diseases.[124] Coalitions have also been effective for an oral cholera vaccine[125] and partnerships have grown up for schistosomiasis,[126] rabies,[127] and Ebola.[128] Several evaluations of public-private partnership mechanisms have reviewed the pros and cons.[129]

IP for drugs – One prominent area has been on intellectual property for drugs. India is experimenting with open source drug discovery for TB drugs, creating a knowledge commons through crowdsourcing.[130] A lot of this work is being done by international organizations. UNITAID has designed the Medicines Patent Pool to stimulate innovation for HIV/AIDS drugs, and the World Intellectual Property Organization has established Re:Search to encourage product development for neglected tropical diseases, and malaria, and tuberculosis.[131] The World Trade Organization's 1994 Trade-Related Intellectual Property Rights agreement (TRIPS) increased basic research on drugs for neglected diseases, though it has not yet led to clinical trials.[132]

Advance market agreements for drugs – These focus not on supply but on demand. One option is an advance market commitment (AMC) or agreement, through which a set of buyers promises to buy a certain quantity of an effective treatment at a certain price, giving the drug developer a sufficient incentive to undertake development. The first AMC was established in 2007 and included five national governments and the Bill & Melinda Gates Foundation, who promised a market for a pneumococcal vaccine. So far, the mechanism has had limited application. Perhaps because of complex implementation issues, national policymakers have generally only participated through their development agencies.[133]

2. ALIGNING NATIONAL INNOVATION AND INDUSTRIAL POLICIES

Countries should engage in STI dialogues on technology catch-up, adoption, and deployment. They can draw lessons from Asia's success with the mass production of electronics, but other relevant examples might include experiences with medical devices and the solar industry, as well as with software, and higher- value agriculture.[134] These dialogues can take advantage of UNCTAD's *Framework for Science, Technology, and Innovation Policy (STIP) Reviews* which can help national governments, civil society stakeholders and international development partners with national catch-up strategies, along with specific policies for harnessing frontier technologies for smarter, more sustainable cities, food security and smart agriculture, and employment generation in smarter factories.

Regional value chains – It should also be possible to create continental value chains. *Africa*, for example, could take advantage of the Africa Free Trade Area to develop local value chains to support the adoption of frontier technologies for such areas as transportation and logistics, fintech, potable water and sanitation, waste to energy, smart cities, affordable housing, and low-cost, high-quality health care. These chains could be supported by procurement programmes and financing mechanisms involving local sovereign wealth funds, pension funds, institutional investors, and guarantee instruments.

Competitiveness – Even affluent countries strive to be among the leaders in the new production regime. Most strategic plans for AI and Industry 4.0 technologies aim to keep national or regional industry competitive. *China* in its 2015 strategy aims to make the country a major manufacturing power in ten years, mastering core technologies in key areas towards the goal of welfare and people's livelihoods.[135] *Germany*, as part of its High-Tech Strategy 2020 Action Plan, aims to be a "lead market and provider of INDUSTRIE 4.0 solutions and services."[136] *Italy* has a policy initiative for Industry 4.0, to contribute to production flexibility, product quality, productivity, and faster movement from prototype to product.[137] *Japan* has a New Industrial Structure Vision that sees the Fourth Industrial Revolution as "the key to a new phase of growth in Japan."[138]

Regulatory environment – Competitiveness requires the right regulatory environment. Countries trying to get into the IoT market are therefore aiming for interoperability and common standards. *India* has a National M2M Roadmap that stresses the importance of such standards to allow its firms to take advantage of IoT opportunities.[139] The AI and big data spaces, on the other hand, generally rely on privacy, security, and data ownership so regulation to facilitate interoperability could reduce the security of data transactions.[140] *Malaysia* is addressing these issues with a plan to set up a central regulatory body to address both interoperability and privacy and security concerns.[141] Many frontier technologies rely on digital infrastructure, platforms and data, so governments will need to guard against anticompetitive practices in digital markets. Open and contestable markets that foster innovation will rely on robust monitoring and enforcement.[142]

Business startups – National and local governments are particularly interested in encouraging new businesses in frontier technology areas.[143] [144] *Thailand* has Startup Thailand, which operates under the Ministry of Science and Technology.[145] *Malaysia* has a special corporation to support small and medium-sized enterprises, with an emphasis on those owned by women.[146] *Brazil* has worked to connect startups with established firms and has a national startup acceleration programme.[147] [148] *Hungary* also provides venture capital for small businesses in the early stages of development.[149] Governments can also help to fund leapfrog technologies in public infrastructure – as has been done in water, telecommunications, and energy.[150]

Foreign direct investment – Industry 4.0 requires a strategic review of investment policies for industrial development – reorienting incentives towards new technologies, facilitating investment and improving screening procedures.[151] Partnerships with foreign firms and FDI can help countries gain footholds from which they can increase indigenous capabilities. In *China*, one study finds that FDI can stimulate the diffusion of new technologies, depending on location and the capacity of the firm to absorb it. Foreign-owned suppliers are more helpful in this regard than foreign customers or competitors.[152] Affluent countries have used centres and hubs to serve as focal points for foreign investment. *Ireland* has the SPOKES programme.[153] *Canada* has Clean Growth Hubs.[154] Transition countries are providing subsidies for FDI. *Lithuania* has Smart FDI.[155] *Slovenia* has the MGRT programme.[156] *Thailand* has Digital Park Thailand which provides both tax and non-tax incentives in a space designed for digital global players to invest and for innovators to emerge.[157]

Preparing for smart factories – Smart factories can combine AI, open-source software, robotics, 3D printing, cloud computing, and big data analytics. These are located primarily in developed countries, but automobile-related smart factories are also springing up in Indonesia, Mexico, Thailand, and Viet Nam.[158] These require world-class high-speed Internet and cloud services integrated into broader digital ecosystems. They will also need a workforce with the skills to thrive in smart workplaces. Technical universities and technical colleges can work with factories to devise training programmes, but national governments should be prepared to defray a substantial portion of the costs, especially in the initial period. The ripple effects of smart factories will extend to second- and third-tier suppliers, but these too will need to smarten up. They will need to receive up-to-the second data via the cloud and, more importantly, make instant adjustments in design, production, and performance characteristics. Governments will need to prepare a local cadre of smart suppliers to support these smart factories. For this purpose, they can learn from the experiences of *Mexico, Viet Nam, Indonesia, and Thailand as well as more developed countries such as Republic of Korea*.[159] Governments, civil society and local stakeholders will also need to develop parallel programmes to deploy frontier technologies for the SDGs, including smart cities and smart farming.

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3. FINDING INVESTORS

Seed-stage technology investors are generally unwilling to invest in products aimed at markets they do not understand, where it may take longer to achieve profitability and where it is harder to sell the company once it has grown. Several alternative models could be further explored.

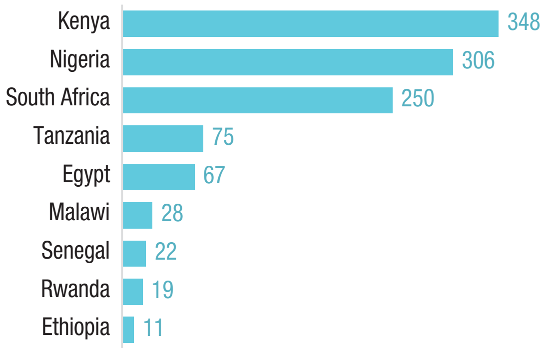
Impact investment – In this case, the investor is looking beyond financial returns. Impact investing is currently focused on developed countries and on mature private companies. Even impact investors targeting developing countries are generally unwilling to invest in risky, unproven technologies and business models. However, given its social and environmental orientation, impact investment could be used to fund STI for the SDGs.

Venture capital – This is appropriate for countries that have some high-tech activity and scope for a critical mass of startups and networks of angel investors.[160]

Crowdfunding – This is usually on a smaller scale and largely takes the form of donations, rewards and preselling. At present it exists mainly in developed countries, focusing on social and artistic causes and activities.

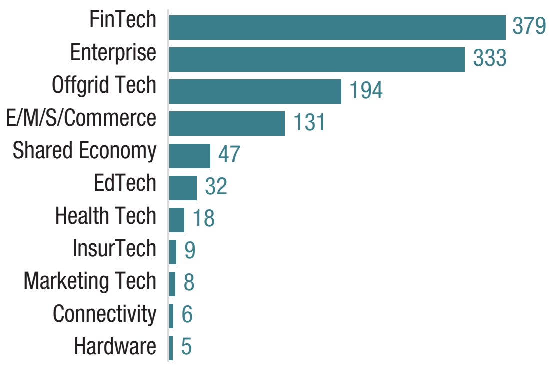
Innovation and technology funds – Financed by the public sector, international donors, development banks or the private sector, these funds have become important instruments for innovation in developing countries. They have the advantage of being relatively fast to introduce and flexible in design and operation. They can also support strategic goals and target particular industries, activities or technologies.

Figure III 18
Equity funding to start-ups in Africa in 2018, selected countries ($ million)



Source: UNCTAD based on Partech (2018).

Figure III 19
Equity funding to start-ups in Africa by sector in 2018 ($ million)



Source: UNCTAD based on Partech (2018).

There have been some successes. In 2018, annual equity funding for tech startups in Africa doubled to more than $1 billion – around 2.5 per cent of total FDI.[161 162] Nine countries received more than $10 million: Kenya, Nigeria, South Africa, Tanzania, Egypt, Malawi, Senegal, Rwanda and Ethiopia (Figure III 18). Some of the largest recipients promote financial inclusion, such as Tala from Kenya which offers loans via a mobile app using non-traditional loan scoring.[163] But there has been less funding for solutions that promote the SDGs. Education and health, for example, received less than 3 per cent of all equity funding (Figure III 19). In the same year, total FDI to African countries amounted to $46 billion.

4. PREPARING THE WORKFORCE

Governments in low- and lower-middle-income developing countries should prepare their workforces with specialized skills in Industry 4.0 technologies. This will require basic literacy and competencies in science, technology, engineering and mathematics – as well as in design, management and entrepreneurship. These countries will also need capacities for complex problem-solving, critical thinking, and creativity. Given that many of these capacities are usually learned by doing, countries will need to foster ecosystems of firms to provide the jobs, training and experience.[164]

Some government plans anticipate increases in employment. Malaysia, for example, has set a goal of 14,270 jobs generated by IoT by 2020.[165] The Republic of Korea sees the potential for IoT development to take the country from 2,700 jobs in 2014 to 30,000 by 2020.[166] Few plans address the concern about AI taking away jobs. An exception is Finland's, which has paid particular attention to the employment implications of AI.[167]

If these labour market transitions are also to achieve decent work and reduce inequality, they will need the involvement of all relevant stakeholders, including trade unions – which have been under pressure with declining membership in many countries.[168] In the United States, precedent indicates that eliminating jobs through changes in production processes is subject to negotiation, but specific clauses in contracts might eliminate that right.[169] In an era of widespread automation, there is even speculation that labour unions may not survive.[170]

On the other hand, labour unions could take up new opportunities to represent workers' legitimate concerns about their jobs. Unions, working with broader coalitions, have achieved some changes and international framework agreements with multinational corporations.[171] Some multi-stakeholder campaigns have had dramatic results: for example, after an energetic, broadly-based public campaign General Motors invested more than $3 billion in Lansing, Michigan.[172] Some labour leaders are viewing automation as an opportunity to establish four-day working weeks and decent pay for everyone.[173] In the United States, unions are drawing up plans to confront autonomous vehicles.[174] These include calls for a workforce transition fund, supported through fees on autonomously driven vehicles.[175] To prepare workers for more automated workplaces, unions are also promoting professional training as an individual right.[176]

Governments can facilitate these dialogues. Germany weathered the 2008–09 recession better than some other countries through a constructive relationship between businesses and unions.[177] In Denmark, the Government established a Council ensuring inclusion of all relevant stakeholders towards the adjustment process to frontier technologies (see Box III 5). In Norway, the Government and the leaders of the trade unions and employers agreed on the Norwegian Strategy for Skills Policy 2017–2021 and established a Skills Policy Council, a tripartite group set up as a result of the agreement, which will follow up the progress. Preparation of workers should start early and will need to be continuous:

Education systems – Governments should promote the study of STEM subjects, particularly among female students, with at least as much attention to post-secondary technical opportunities as to university-level training. Schools can use computer-based systems, and educators may be able to use AI tools to personalize the learning experience and create more equal outcomes. Apprenticeship programmes that combine work- and school-based learning, for example, can support young people in transitioning from school to work. The *United Kingdom* has a plan for growing the AI-ready workforce through 20,000 apprenticeships to be in place by 2020.[178]

Lifelong learning – The transition to frontier technologies and onwards will be a continuous process. This training and re-training of workers will increasingly become the joint responsibility of governments, employers and workers. Governments may also support workers in job transitions with job matching, personal counselling and placement services. The *EU's* vision for "resilient, sustainable and competitive manufacturing" plans both to attract "young talents" and to retrain older workers.[179] *Malaysia's* Draft National Industry Policy Framework emphasizes upskilling and reskilling labour pools.[180]

High-level expertise – As well as a broadly skilled workforce, countries will need concentrated, high-level expertise – though this to some extent will foster an elite and worsen inequality. *China's* 2025 strategy seeks high-level professional and technical personnel, including university-trained advanced manufacturing engineers, researchers, technicians, and "interdisciplinary professionals."[181] Under *Italy's* policy initiative for Industry 4.0, by 2020, 200,000 students and 3,000 managers will be qualified in Industry 4.0 topics.[182]

Gender balance – Expanding a highly skilled specialist workforce, should allow better representation of women and other groups normally underrepresented in science and engineering careers. Some countries see the potential for AI systems to increase employment opportunities for disadvantaged groups, by overcoming physical or cognitive limitations.[183]

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Box III 5

Social dialogue in Denmark for decent work and less inequality

To prepare for the future of work, Denmark has established the Disruption Council. This comprises ministries, social partners and representatives of society. The Disruption Council's initiatives include:

Agreement on a new unemployment benefit system

The agreement changes the rules for self-employed and atypical workers to bring them more in line with those for employees when it comes to unemployment benefits and social assistance. This should offer greater security for everyone regardless of their form of employment, and prepare for a more diverse labour market comprising fewer permanent employees and more freelancers, platform workers and partially self-employed individuals.

National competence panel for higher education programmes

Higher education programmes need to respond to the changing competence requirements in the labour market and adjust their curricula accordingly. For this purpose, the Government decided to establish a national competence panel which will inform and advise the Minister of Higher Education and Science and higher educational institutions about changes and trends in labour market demands.

Monitoring and supervision of competition conditions and tech giants

To support fair competition and consumer conditions, the Government plans to strengthen the Competition and Consumer Authority's supervision of digital platforms. The aim is to assess and detect abuses by big platforms in their business conditions and pricing – and potential harm for competition especially for micro-enterprises, SMEs and consumers.

Assistance for the most disadvantaged unemployed

The Council recognizes that there should be different paths into the labour market for those who have been outside the labour market for long periods. In this regard, the Government intends to launch a partnership to ensure closer cooperation between job centres, temporary work agencies and platform companies. The partnership is to provide the most vulnerable unemployed persons with temporary employment opportunities through which they can learn tasks and gain competencies.

Source: UNCTAD based on VIS (2017), Alsos et al. (2019), The Danish Government (2019)

5. PROVIDING INCOME SUPPORT

If joblessness becomes chronic, some observers foresee the need for stronger mechanisms of social protection and income distribution.[184] Social protection systems support workers during labour market disruptions. However, only a third of the world's population is covered by comprehensive social security, while over half of the workforce has not social security at all.[185] In addition, social protection systems worldwide are under pressure – due to population ageing, smaller tax bases and low interest rates.

To address these challenges, a number of schemes have been proposed. They include negative income tax, universal basic income, and workfare.

Negative income tax

In a normal system of income tax, citizens start to pay tax beyond a certain level of income. In a system of negative income tax (NIT), if people are not reaching this threshold the government pays them a percentage of the difference between that threshold and their income.[186] It is designed so that those who work make more money than those who don't, and is simpler than providing subsidies for specific items like food or housing while still offering incentives for work.[187] Some studies show that the evidence on NIT is mixed, with no overwhelming case for or against.[188] Similarly with modelling exercises. One study indicated that NIT can sharply reduce inequality and poverty, though at the expense of output.[189] Another predicted that in the *United States* NIT would show significant average welfare gains, while increasing the proportion of high-productivity workers in the labour supply.[190] Specific proposals for NIT have been made for *Spain* and *Germany*.[191]

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Universal basic income

Another approach is for the government to offer everyone a minimum subsistence amount – a universal basic income (UBI). The idea has been around for centuries, with proponents from across a broad range of the political spectrum, from Friedrich Hayek to John Stuart Mill.[192 193] But given the potential for widespread job losses through automation, the idea is now being considered a realistic option. Some have argued that because the digital economy will increase inequality such mechanisms will be essential.[194] The principle has appeal in the case of people who face specific barriers to employment such as those with disabilities.[195]

> Only a third of the world's population is covered by comprehensive social security, while over half of the workforce has not social security at all

The discussion on UBI has exploded in cyberspace.[196] Others call it a "false promise",[197] or argue that the focus on cash transfers distracts attention from considerations of overall quality of life.[198] There are also feminist and indigenous perspectives.[199]

UBI lends itself to experimentation.[200] Silicon Valley firms have expressed interest in the mechanism and offered to fund trials.[201] The city of Stockton, California, once described as "America's foreclosure capital," has started its own experiment, distributing $500 a month to 130 residents of a low-income neighbourhood.[202] Utrecht[203] and Barcelona[204] also have pilot projects. The Canadian province of Ontario started an experiment but cancelled it within a year after a change in political leadership.[205 206] The results of an experiment in Finland showed that the unemployed individuals who received monthly incomes were happier and healthier than a control group, but only marginally more likely to find work.[207] This result was not surprising since unemployment often arises from low skills, difficult life situations, or health concerns.[208]

Proposals are by no means limited to affluent countries. Based on experience in India and Namibia,[209 210] UBI has been proposed for the huge refugee populations in Syria.[211] The case has also been made for application in other low- and middle-income countries.[212] Some parts of the developing world have implemented their plans, including Macao, China, and the Islamic Republic of Iran. Poland has a programme, and in the Ukraine a private company is issuing credits.[213] Alaska has a permanent fund.[214] Several Native American nations have also distributed funds from joint investments, with positive effects.[215]

Public employment

Another way to address a shrinking private workforce is to increase the public workforce. One option sometimes known as "workfare" includes public employment programmes on roadbuilding or other infrastructure.[216] In India, the benefits of such employment have been found to be large and greatly underestimated.[217]

A second approach focuses on public employment. This can usefully be expanded for jobs that invest in people, such as day-care, elder-care, education, and healthcare.[218] These are skilled jobs, that require more education and training than workfare jobs. They help to support households in the middle of the income scale and can thus reduce inequality through both direct and spillover effects.[219] Other more conventional steps to ameliorate lack of jobs and benefits include universal healthcare, affordable education, and accessible childcare options; in short, a broader social safety net.

6. WEALTH REDISTRIBUTION

Paying for any of the options above will require increased resources. There have been a number of proposals for widening taxation. The most directly relevant is a "robot tax" which would gather income from the technologies that replace workers. If these workers were unable to move to non-routine occupations, this would replace the income taxes they would otherwise have paid. For the United States, for example, it has been suggested that a robot tax would be an optimal strategy when the people displaced were still active in the labour force, but not after they had retired.[220] Devising robot or automation taxes raises a number of legal and other issues, starting from the legal definition of robot and automation, and deciding how to impute an equivalent income value for robot activity. It might also be possible to grant robots a "tax personality".

Some researchers have dismissed these ideas since they could discourage efforts to increase productivity, preferring instead to rebalance taxation between capital and labour income.[221] If the aim is to ensure that taxation is neutral between employing machines or people, this could be accomplished by removing corporate tax deductions for automation, and creating an automation tax to pay for unemployment schemes.[222]

Frontier technologies such as AI and blockchain open up the option of taxing cryptocurrency operations – which would better target the relevant populations, activities and behaviours.[223] Nevertheless, the increasing use of automation and AI in tax preparation and collection systems could have unintended consequences; this needs to be carefully monitored to ensure that no one is negatively affected by the actions of automated agents.[224]

Rather than taxing individuals or technologies through their income it might be more effective to tax the resulting wealth. This principle received a lot of attention following the publication of Thomas Piketty's *Capital in the 21st Century*, in which a prominent recommendation was a global wealth tax.[225] He acknowledges that this may be impractical at present but would addresses the underlying dynamic in the long run. This proposal has generated a remarkable range of comment.[226] Critics say it would hurt everyone by slowing down growth and that the same effect on distribution can be achieved by existing taxation of capital gains and estates.[227]

7. ENSURING EQUITABLE ACCESS TO PATENTED TECHNOLOGIES

Many of the benefits of frontier technologies could be retained by a privilege few through the use of intellectual property rights. One response to this is compulsory licensing – through which a government or company can produce a patented product or process without the consent of the patent owner. The WTO Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) allows for this, covering the limitations and flexibilities of patent rights, but this is widely considered as an option of last resort and is rarely used.

For solving 'transactional bottlenecks', private actions by industry may be more effective than statutory interventions.[228] Alternative collaborative arrangements include patent pooling, clearing houses, and open source licensing. Governments can also buy out patents.

At the same time, governments can finance R&D while requiring that the benefits serve the public good. This could include research grants and tax credits along with prizes and advance purchase commitments for innovative products that address sustainable development concerns. At the same time, international scientific collaboration can ensure that the skills in data analytics and machine learning tools are more evenly spread between countries.

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Frontier technologies can increase productivity and enable economic diversification in developing countries, but they are also likely to affect inequalities within and between countries. The outcomes will vary by sector and depend on the capacities of countries, and on their policies and strategies. Some jobs and functions may become redundant while other jobs would be created. In the short term, some workers would lose their jobs and would have to find other occupations. But in the medium term there might be consistently fewer jobs in certain occupations and more in others. Change may also be faster than people's ability to adapt; some may never do so and will need long-term support.

Nevertheless, experience shows that new technologies permeate over time to the various economic sectors and social activities and that governments can limit negative impacts on inequality by preparing people, firms and institutions for change. Overall, governments need to facilitate the use, adoption and adaptation of frontier technologies while mitigating the potential adverse effects.

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50 Paquette, 2019; *Radiology Business*, 2020

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54 ISCO-08 group 5 (service and sales) is included in the medium skill level, while this group is traditionally in the low skill group in the polarization literature. The approach adopted in this report takes into consideration the construction logic at the basis of ISCO-08 which puts together groups 4 to 8 at the same skill level. The analysis assuming group 5 as part of low skill group does not change the conclusion illustrated in the figure.

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CHAPTER IV

INNOVATION WITH EQUITY

Frontier technologies have huge potential for improving people's lives and protecting the planet, but social and economic problems such as poverty and inequality are complex, and technology is rarely a solution on its own.

Frontier technologies, as any technology, can affect inequalities in the user's perspective through 1) Differential access to the benefits of these technologies and 2) Their potential unintended consequences.

Many of the concerns raised on the use of frontier technologies are related to biased design and the unintended consequences of AI, and inequalities and ethical considerations of gene editing.

Developing countries face three main challenges in promoting equal access to the benefits of frontier technologies:

- **Higher income poverty**
- **Digital divide**
- **Shortage of skills**

To overcome these challenges, Governments and the international community need to guide new and emerging technologies so that they support sustainable development and leave no one behind, foster supportive innovation ecosystems, and deploy technologies at scale.

This chapter considers frontier technologies from the perspective of final users. It examines how people are affected by goods and services that embody these technologies. In particular it considers how the poor may be disadvantaged, either by lack of access, biased design or just unintended consequences. Governments can direct technology towards sustainable development by extending the access to digital infrastructure and STI skills and scaling up innovations that target the poor.

A. TECHNOLOGIES AFFECTING INEQUALITIES THROUGH DESIGN AND ACCESS

Frontier technologies have huge potential for improving people's lives and protecting the planet (Box IV 1). During the COVID-19 pandemic, for example, AI and big data have been used for screening patients, monitoring the outbreak, tracking and tracing cases of the disease, predicting its evolution and assessing infection risks. Other examples have ranged from the use of IoT to monitor the quality of groundwater in Bangladesh, to the use of drones to deliver medical supplies to remote communities in Rwanda and Ghana.[1]

But technology is rarely a solution on its own. Problems such as poverty, hunger, and climate change, or inequalities in health or education are inevitably complex and multidimensional.[2] Technology is neither inherently good nor bad; it is a means to an end. Technology, frontier or otherwise, may support initiatives of all kinds, social, political, or environmental, but all technology needs to be used carefully if it is to help rather than hinder.

Developers should also be mindful that the ways that they design, and that people use, technologies can have unintended consequences (For a detailed discussion see Annex C. How technologies affect inequalities in the user's perspective). Given that many frontier technologies have general-purpose usages, they could have a significant impact on the economies and societies as well as on the development of other technologies, and trigger multiple side effects.[3]

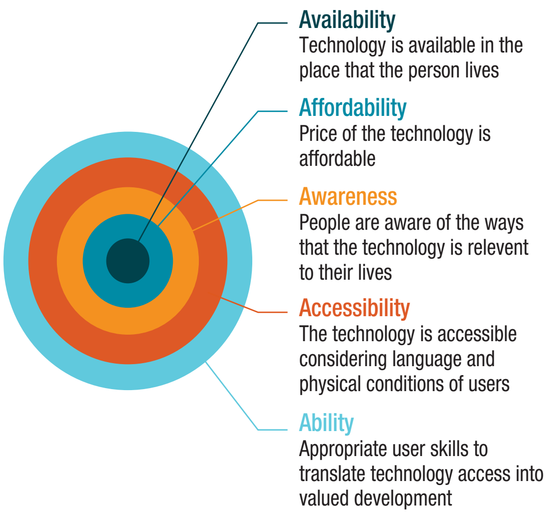
The impact of these technologies on inequalities will also depend on how they are produced and distributed. Initially, they are likely to benefit the better off. When companies develop new technologies for goods and services they focus on wealthier consumers who can bear higher initial prices and thus benefit first while contributing more to further development.

One of the most critical aspects is access – which can be considered to comprise a combination of "five A's": availability, affordability, awareness, accessibility, and ability for effective use (Figure IV 1).[4] An example is Amazon's AI virtual assistant Alexa which is available in many countries but not yet in all languages. In many countries, it can only respond to people who speak English. It also limited to those who can pay for the hardware and the bandwidth.

Access to technology can also be restricted by social norms – for women, ethnic minorities and other disadvantaged groups, even within the same household. New technologies pose particular challenges to women, given their underrepresentation in STEM fields and the persistent gender gap in access to, and use of, digital technologies.

Technologies are likely to have an effect on disparities, but inequalities can also shape

Figure IV 1
Five as of technology access



Source: UNCTAD based on Roberts (2017) and Hernandez and Roberts (2018).

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technologies – so that they reflect, reproduce and perhaps amplify each society's specific interests and priorities.[5] Currently most technologies are created by firms in the global North and predominantly by men.[6] Inequalities also affect the direction of innovation in ways that could further increase disparities; for example, by focusing on the demands of the rich and crowding out innovation towards solutions that benefit the poor.

Box IV 1
Frontier technologies for the SDGs

Frontier technologies are expected to become cheaper and easier to access and use. Some of the most important developments have been in energy. The cost of solar panels has fallen by a factor of more than 100 over the last 40 years, and by 75 per cent over the past 10 years.[7] Low-cost, high-efficiency solar panels can be used for household rooftop solar installations as well as for village-level micro- and mini-grids. Household rooftop two-year rent-to-own plans are priced as low as $6 per month.[8] Over the coming years, there are likely to be further breakthroughs in the design and manufacture of photovoltaic cells and battery storage systems, with possibly the advent, in the not-too-distant future, of printed organic solar cells.[9 10]

Frontier technologies make it possible to shift from large, centralized water and power plants, for example, to small-scale, distributed delivery systems such as village mini-grids, rooftop solar systems, and village or urban neighbourhood water purification and distribution kiosks. These smaller scale distributed facilities are less expensive to install and operate. They also potentially allow for more community control.

Other frontier technology breakthroughs include:

COVID-19 Management – Rwanda is deploying high-tech robots produced by the Belgian company Zorabots,[11] to "perform a number of tasks related to COVID-19 management, including mass temperature screening, delivering food and medication to patients, capturing data, detecting people who are not wearing masks, among others".[12] It is also using sophisticated mathematical algorithms developed by a local epidemiologist to minimize the cost and maximize the effectiveness of COVID-19 testing.[13]

Water purification – With respect to SDG 6 on clean water and sanitation, there is now an array of high-performance, affordable water purification filters. These can covert polluted fresh water, brackish water, and saltwater into WHO-quality potable water. Some filters can even be 3D printed.[14] Further innovations in this area could include the production of filters on-site and for personal use, making them more readily available to remote communities.

Off-grid solar-powered services – In remote rural areas of Rwanda, Zambia, and India, the company Vanu is providing off-grid, solar-powered, voice and data services.[15] These are based on "ground-breaking research in software radio at MIT," For communities without grid power or Internet connectivity, these services are providing many benefits to communities, through advances in agricultural extension (SDG 2), telemedicine (SDG 3) and distance education (SDG 4).

Waste management – Waste-to-energy processes generate low-cost, renewable energy from animal and human waste, organic waste from farming and food processing, industrial waste, and municipal garbage. These frontier technologies also mitigate environmental damage from landfill and wastewater run-off into ground and surface water.[16]

Sewer maintenance – A robot developed in India cleans sewer manholes remotely using computer vision and robotic arms. The robots do away with the inhuman practice of manual scavenging. The company that developed and deployed these robots is also training the scavengers, who are primarily from the lowest castes, to become robot operators, thereby giving their families a life of dignity.[17]

Earthquake risks – Machine learning coupled with drone and satellite imaging can be used to develop risk maps for rapidly growing cities in Africa and elsewhere. AI can help assess which buildings are at high risk of collapse and therefore in need of retrofitting before the next earthquake or typhoon. New and more affordable materials coupled with new construction technologies can enable poor households to retrofit houses that are in danger of structural collapse.[18]

These examples are only the tip of the frontier technology iceberg. There are hundreds if not thousands of solutions spanning the entire range of frontier technologies and SDGs.

Source: UNCTAD.

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Technological change is also shaped by gender inequalities. This is partly because men have been more likely than women to study STEM subjects and have STEM careers, but the bias also extends into the marketplace. One study concluded that women found it ten times more difficult than men to secure investment for their technological innovations.[19] It is also generally difficult to secure funding for technologies that address women's issues and priorities.

B. RISKS OF BIAS AND DISCRIMINATION

Many of the concerns raised on the use of frontier technologies are related to biased design and the unintended consequences of AI, and inequalities and ethical considerations of gene editing.

1. AI ALGORITHMS WITH BUILT IN BIAS

Some products have built-in biases, designed or learned. Human beings also take biased decisions, but they are more accountable and better able to explain their reasoning. AI, for example, can make biased decisions on social questions for, say, the entitlements to benefits or automated legal aid for immigration applications. In the United Kingdom, a survey in 2020 found that nearly half of local councils had used computer algorithms to help make decisions about benefit claims, on who gets social housing and other issues – despite concerns about their reliability.[20]

AI can also perpetuate stereotypes and reduce the benefit of products for women. For example, voice-recognition in cars that reacts better to lower-pitched voices,[21] fitness trackers that underestimate predominantly female-associated activities such as housework,[22] and translation technologies that are gender-biased.[23]

In 2014 in the United States, an AI system for recruiting software engineers was found to penalize résumés that contained the word "women".[24] This bias was not coded into the algorithm, but the AI learned it from the company's historical recruitment pattern. After identifying the problem, a fix was introduced. Nevertheless, there were no guarantees that the system would not learn other biases and it was abandoned. Similar biases can affect other groups. For example, in 2016 in the United States, an AI system to assist judges in making better sentencing decisions based on predictions of the likelihood of criminals re-offending was found to be biased against ethnic minorities.[25]

Another bias issue concerning public services is that some groups are overrepresented in government databases especially those for social services.[26] This overidentification arises as people applying for services have to provide more information about themselves. For instance, when seeking treatment for drug addiction, people from lower socio-economic backgrounds are more likely to use public clinics, while wealthier people can get help privately. Governments thus tend to have less data on the wealthy who can thus remain under the radar for behaviours that might raise red flags.[27] This could matter when decisions are made on sensitive issues. For example, if there are concerns about child welfare poor people are more likely to lose custody.

Algorithms also affect which groups are exposed to certain advertisements.[28] One study found that being signed into a Google account as a woman reduced the likelihood of seeing advertisements for higher-paying positions.[29] This finding was echoed in an experiment on Facebook, where ads for housing and employment opportunities were skewed along racial and gender lines.[30] Another empirical study found that cost-optimizing algorithms were showing women fewer ads promoting job opportunities in STEM fields because women were considered a prized demographic and ads of expensive products crowded out the job opportunity ads.[31]

Biases within AI systems can arise in a number of ways, either because they employ biased algorithms or they use biased data for training.[32] Biases may also arise from the use of fuzzy data where there are no clear binary choices. For example, screening tweets from Twitter, or images from Instagram, or videos on TikTok, require judgements on social acceptability. An AI system has to be programmed with, or develop, a measure – which will inevitably be fuzzy and socially dependent.[33] Some of the areas to consider are listed in Table IV 1.[34]

Efforts may be made to hide sensitive fields from algorithms, such as those on race and gender. But learning algorithms can use probabilistic methods to recreate these fields and make discriminatory decisions. Artificial agents learning from human-derived data will often learn human biases, both good and bad.[35]

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Table IV 1
Types of biases in AI systems

Type	Description
Historical Bias	Historical bias is the already existing bias and socio-technical issues in the world and can seep into from the data generation process even given a perfect sampling and feature selection.
Representation Bias	Representation bias happens from the way we define and sample from a population.
Measurement Bias	Measurement bias happens from the way we choose, utilize, and measure a particular feature.
Evaluation Bias	Evaluation bias happens during model evaluation.
Aggregation Bias	Aggregation bias happens when false conclusions are drawn for a subgroup based on observing other different subgroups or generally when false assumptions about a population affect the model's outcome and definition.
Population Bias	Population bias arises when statistics, demographics, representatives, and user characteristics are different in the user population represented in the dataset or platform from the original target population.
Simpson's Paradox	According to Simpson's paradox, a trend, association, or characteristic observed in underlying subgroups may be quite different from association or characteristic observed when these subgroups are aggregated. This can bias the analysis of heterogeneous data that is composed of subgroups or individuals with different behaviours.
Sampling Bias	Sampling bias arises due to non-random sampling of subgroups.
Behavioural Bias	Behavioural bias arises from different user behaviour across platforms, contexts, or different dataset.
Content Production Bias	Content Production bias arises from structural, lexical, semantic, and syntactic differences in the contents generated by users.
Linking Bias	Linking bias arises when network attributes obtained from user connections, activities, or interactions differ and misrepresent the true behaviour of the users.
Temporal Bias	Temporal bias arises from differences in populations and behaviours over time.
Popularity Bias	Items that are more popular tend to be exposed more. However, popularity metrics are subject to manipulation—for example, by fake reviews or social bots.
Algorithmic Bias	Algorithmic bias is when the bias is not present in the input data and is added purely by the algorithm.
User Interaction Bias	User Interaction bias is a type of bias that can not only be observant on the Web but also get triggered from two sources—the user interface and through the user itself by imposing his/her self-selected biased behaviour and interaction.
Presentation Bias	Presentation bias is a result of how information is presented.
Ranking Bias	The idea that top-ranked results are the most relevant and important will result in the attraction of more clicks than others.
Social Bias	Social bias happens when other people's actions or content coming from them affect our judgment.
Emergent Bias	Emergent bias happens as a result of use and interaction with real users. This bias arises as a result of a change in the population, cultural values, or societal knowledge, usually sometime after the completion of the design.
Self-Selection Bias	Self-selection bias is a subtype of the selection or sampling bias in which subjects of the research select themselves.
Omitted Variable Bias	Omitted variable bias occurs when one or more important variables are left out of the model.
Cause-Effect Bias	Cause-effect bias can happen as a result of the fallacy that correlation implies causation.
Observer Bias	Observer bias happens when researchers subconsciously project their expectations onto the research.
Funding Bias	Funding bias arises when biased results are reported in order to support or satisfy the funding agency or financial supporter of the research study.

Source: Mehrabi et al., 2019.

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2. GENOMIC INEQUALITIES

The development and application of gene-editing technology should bring a number of benefits but they are likely to be unevenly distributed – with three main sources of inequalities: R&D inequalities, data inequalities, and therapy inequalities due to affordability.

R&D inequalities

Most human genomic centres around are in developed countries; very few in developing countries, which have also produced only few biomedical publications.[36 37] This is largely due to the high costs of equipment and the lack of scientific personnel with sufficient training and experience.[38] But developing countries may also hesitate to invest in genomic research given that they have more pressing health-related issues such as poverty, infectious diseases, and the lack of basic infrastructure.

Data inequalities

Most genomic data has been gathered from people in developed countries, very little from developing countries.[39] Data are typically produced through genome-wide association studies (GWASs) which scan the genomes of many people to find variations associated with a particular disease. In these studies, 96 per cent of subjects have been of European descent.[40]

Similarly, Africa carries the highest burden of both infectious and non-communicable diseases, and hosts the greatest genetic diversity within its population, but only seven of the thousands of GWASs, have been conducted exclusively on African participants.[41] By 2017, less than 10 per cent of GWAS data were coming from African populations, although this proportion is increasing.[42] This is mainly because Africa lacks the necessary biomedical research infrastructure or computation resources for large-scale genomics studies. In collaborative research, African scientists generally only participate in sample collection.[43] This research has received little support from governments but there are some initiatives to engage Africa in genomics research – such as the H3Africa Consortium, the Wellcome Trust DELTAS programme, and the GSK Africa OpenLab.[44]

Other developing regions have also been under-represented. India, for example, has 20 per cent of the world's population yet its citizens have provided only 1 per cent of genetic data.[45] Several startup companies are seeking to gather more data from Asian populations. For example, GenomeAsia 100K aims to create reference genomes of all major Asian ethnic groups starting with the sequences of 100,000 people.[46]

Therapy inequalities due to non-affordability

There is a similar imbalance in clinical trials. Most have been carried out in the United States (63 per cent) and Europe (23 per cent). Most non-clinical gene-editing studies have also been conducted in the United States (55 per cent), and China (19 per cent).[47] This is mainly because gene therapy is costly. Drug companies need to recoup the costs of initial development, and of production which has to be tailored to each patient so is labour-intensive and expensive.[48] Companies will also need to follow up with patients for years. The rarer the disease, the fewer the eligible number of patients to cover the costs and the more expensive the treatment. Glybera, for example, was developed to treat adults with lipoprotein lipase deficiency, but at $ 1.1 million per treatment was only sold once in Europe before it was withdrawn from the market due to lack of demand.[49]

3. GENE EDITING AND INTELLECTUAL PROPERTY

Gene-editing is also constrained by patents.[50] For some breakthrough biological research tools, such as recombinant DNA and small interfering RNAs, companies and academic institutions can get non-exclusive licenses. But in the case of CRISPR each patent-owning institution grants exclusive licenses only for specific fields of use.[51] There has already been a well-publicised patent battle over

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CRISPR technology between the Broad Institute/Massachusetts Institute of Technology and the University of California, Berkley.[52]

Patents on gene editing technologies are primarily held in large industrial firms or by academic institutions, many of which go on to form business ventures. Most are in the United States but there are increasing numbers in China.[53] This raises the prospect of monopoly ownership of technologies which could limit their contribution to achieving the SDGs, particularly those related to food production and health.

Article 27.2 of the TRIPS Agreement states that "[m]embers may exclude from patentability inventions, the prevention within their territory of the commercial exploitation of which is necessary to protect public order or morality, including to protect human, animal or plant life or health or to avoid serious prejudice to the environment, provided that such exclusion is not made merely because the exploitation is prohibited by their law." However, no legal guidance is provided on what constitutes morality, which is influenced by the cultural norms of different countries.

Patents are intended to encourage innovation and incentivize investment in research, but they can also stifle further innovation, limiting access to critical genetic information. International cooperation in genomic research will need to address patent protection issues to make gene therapies more accessible and affordable for sustainable development.

4. ETHICAL QUESTIONS IN GENE EDITING

The principle of using this new technology for genetic enhancement could also be very divisive since it raises questions of what constitutes an ideal human being. This could result in the development of an underclass of people who cannot afford genetic treatment.[54]

Moreover, if this technology is used to eliminate genetic disabilities it sends a clear message to those in the disabled community about society's view and value of their lives.[55] [56] The unregulated use of germline gene editing would result in the termination of pregnancies based on these discriminations.[57] [58] In place of necessary societal change, germline gene editing proposes a technological solution. This furthers the rhetoric that the disabled community has little to offer society because their disabilities, viewed as problems, can be "fixed" with technology. An additional complex conversation concerns who decides what conditions germline gene editing would target.

The process of gene editing also has specific implications for women.[59] Research in germline gene editing requires massive numbers of human eggs, and the long-term health effects of egg harvesting are not well known. Current forms of assisted reproductive technologies already put women at risk for obstetric and other maternal health complications.[60] Germline gene editing runs the same risks as both preimplantation genetic diagnosis and *in vitro* fertilization. Women partaking in germline gene editing studies may also run unforeseen risks if edited foetal DNA enters the maternal bloodstream.[61] It is important to consider the potential health risks for women in developing and implementing the technology.[62]

THE LEGAL, ETHICAL AND MORAL BOUNDARIES OF USING GENETIC TECHNOLOGIES ARE INCREASINGLY UNCLEAR, CREATING OPPORTUNITIES FOR THEIR MISUSE AND ABUSE

Germline gene editing encourages the belief that parents should risk everything to give their child the best start to life. This could put them under pressure to use the technology to optimize the life chances of their children.[63] This is worrisome eugenic vision for the future – one where the human population is divided into two species: superhuman edited races and backward unedited races.[64]

It could also have military implications if research can be weaponized to target and harm specific population groups. Gene-editing could also be used by armies to select for intelligence combined with physical strength and resistance to injury and pain.[65] The legal, ethical and moral boundaries of using genetic technologies are increasingly unclear, creating opportunities for their misuse and abuse.

C. CHALLENGES FOR DEVELOPING COUNTRIES

Developing countries face particular challenges in promoting equal access to the benefits of frontier technologies. Three main issues are the higher level of income disparities, digital divides and shortage of skills.

1. HIGHER INCOME POVERTY[66]

The major issue is the higher level of income disparities in developing countries as compared with developed countries and the large share of the population in the lower end of the income distribution, with persistent pockets of extreme poverty, particularly in rural areas. Income disparity translates into inequalities in social and environmental dimensions, for example in health, education and higher vulnerability to disasters, which are further magnified by social biases and discrimination, affecting women and girls disproportionately. As a result, access to goods and services is inherently more difficult for a larger share of the population in developing countries. The effect of affordability of technology on its broader access is a well-established fact in the deployment of digital technologies.[67] This challenge is common for access to any product or technology – from clean water and sanitation to digital learning, from bicycles to air tickets.

Poor communities are harder to reach. In this case the barriers are not technological but economic and social. Frontier technologies make it technically possible to disperse many important services or products to poor communities. Nevertheless, installing, managing, operating, repairing, financing, and collecting payments from hundreds, if not thousands, of widely dispersed facilities will be logistically and administratively complex.

> Poor communities are harder to reach. In this case the barriers are not technological but economic and social.

Consider the provision of safe, reliable, affordable access to potable water. Scientists have developed nano filters that convert saltwater, brackish water or polluted fresh water into WHO-quality potable water.[68] But for a purification mechanism to be operational it needs to be combined with pumps, hoses, and cisterns. It also needs a financially sustainable business model for distributing water to customers, collecting payments, and operating, maintaining and repairing the equipment.

The scientist who invented the nano filter is unlikely to leave the lab to devote time, money, and effort to organizing and managing these tasks in hundreds or potentially thousands of scattered communities. Someone needs to undertake this work – whether an equipment supplier, a local or international NGO, a social enterprise, or community members themselves.

There are similar challenges in marketing new agriculture technology to smallholder subsistence farmers. Many live in poorer, more remote regions with inadequate or non-existent infrastructure that makes them expensive to reach. Moreover, they can be reluctant to depart from traditional practices due to local, culturally-specific beliefs and socio-economic values.[69] And those who want to take up new technologies may be unable to afford them, or subsequently gain access to markets that would enable them to convert greater productivity into higher incomes.

All too often, it is assumed that once an appropriate frontier technology solution has been developed deployment will follow automatically, or that the scientists and engineers who invented a technology can just use online platforms to identify people and communities who need it. Unfortunately deploying technology is neither simple nor automatic and cannot be relegated to an afterthought.

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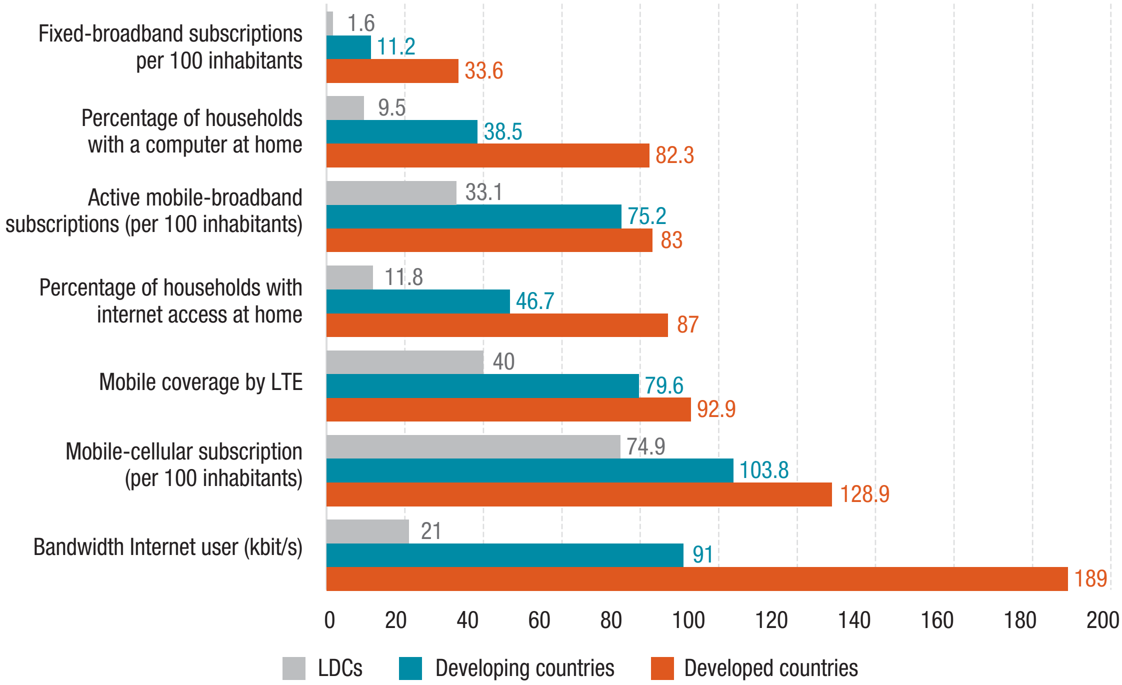
2. DIGITAL DIVIDES

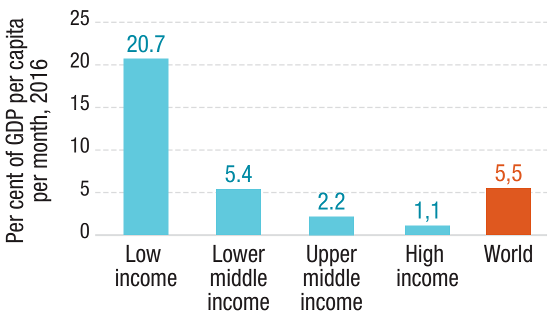
Many frontier technologies rely on steady, high-speed fixed Internet connections, such as fibre optic cable, or on high-speed mobile connections. In the case of broadband many developing countries do not have adequate digital infrastructure, and for most of their people Internet costs are prohibitive. Almost half of the world's population remains offline and there are huge regional, gender and other divides. The gaps between countries are shown in Figure IV 2. In developed countries in 2018, around 33 per cent of the inhabitants had fixed broadband subscriptions, while in developing countries the proportion was only 11 per cent. In 2018, around 80 per cent of people in Europe were using the Internet, while in Sub-Saharan Africa the proportion was only 25 per cent and in the least developed countries only 20 per cent.

Figure IV 2
Gaps in digital access, 2018



Source: UNCTAD based on ITU (2018, 2019).

Figure IV 3
Price of 1 gb of data, percentage of GDP per capita per month, 2016



Source: UNCTAD based on World Bank (2018).

Progress has been faster for mobile internet connectivity. This is because the upfront costs for mobile network infrastructure are lower, especially for the last-mile connection. Globally in 2018 there were 83 active mobile broadband subscriptions per 100 inhabitants, though the number was lower in developing countries at 75, and in the least developed countries at 33.[70]

These disparities are reflected in bandwidth use. People in developed countries use twice as much bandwidth as people in developing countries and nine times more than those in the least developed countries. Data use also varies significantly between developing countries. For one mobile phone

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provider in Africa and Western Asia, for example, data use ranges from 200 MB per person per month in Yemen to more than 5 GB in the Islamic Republic of Iran.[71]

These differences in use reflect differences in cost. In high-income countries the monthly price of 1GB of data represents, on average, 1.1 per cent of GDP per capita per month, but in low-income countries this proportion is more than 20 per cent (Figure IV 3). There are similar cost issues for mobile broadband. In most developed countries, the cost of 1.5 GB of use remains below 2 per cent of per capita GNI, but in the least developed countries the cost is higher; it costs between 5 and 10 per cent in 15 of these countries, 10 to 20 per cent in another seven, and above 20 per cent in the other nine.[72]

People's Internet use is often constrained by high prices. In Argentina, Colombia, Ghana, Guatemala, Paraguay, Peru and Rwanda, more than half of households limit their Internet use because of the cost.[73] Moreover, even before they connect, many people still struggle to buy a device: in low- and middle-income countries, many people do not own a phone because they cannot afford one.[74]

3. SHORTAGE OF SKILLS

It is not necessarily easy to use frontier technologies. Many require at least literacy and numeracy skills, and an aptitude for learning by doing. As more services, whether from the private sector or governments, move online, people without either the connections or the necessary skills or aptitudes are increasingly at a disadvantage. Digitalization of public services and the mandatory use of digital channels to access social services and benefits, can improve efficiency and transparency, but could also punish the poorest.[75]

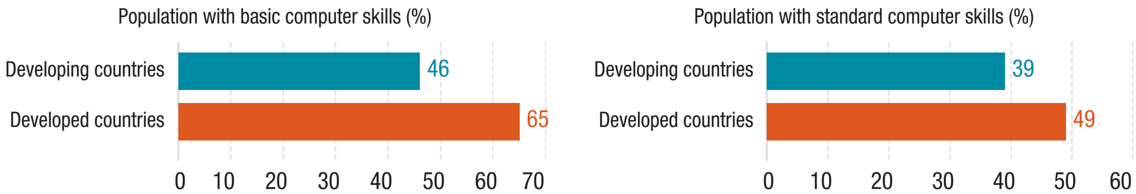
To some extent low literacy skills are now easier to overcome, by voice control of smartphones for example. In 2018, in high-income countries 74 per cent of mobile connections were through smartphones. In sub-Saharan Africa the proportion was only 40 per cent, but the situation has been improving: between 2014 and 2018 smartphone use in sub-Saharan Africa increased by 28 percentage points.[76]

Nevertheless, benefiting from these technologies requires skills beyond basic literacy.[77] At the very least, these digital skills include the ability to understand digital media, to find information, and use these tools to communicate with others. This requirement has been highlighted during the COVID-19 pandemic when people needed digital skills not just for communicating, but also for finding information, buying food and supplies online, and using new software and applications. Users also need to be critical of the content that is delivered through digital platforms so as to counteract malicious misinformation and the use of fake news.

Most people are relative beginners: 30 per cent of individuals lack basic skills such as using copy and paste tools.[78] Only two out of five people have standard skills such as installing and configuring software according to their needs. Typically in developing countries, the basic and standard skills are on average 10 to 20 percentage points lower than they are in developed countries (Figure IV 4) though, as technology develops, the skills required and the fault lines between users and non-users are likely to shift.[79]

Without specific policies, strategies and programmes to promote the adoption of these technologies, developing countries risk falling further behind – aggravating and perpetuating inequalities between countries.

Figure IV 4
Gaps in digital skills



Source: UNCTAD based on ITU (2018, 2019).

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D. DIRECTING TO SUSTAINABLE DEVELOPMENT

Public policy needs to guide innovation in new and emerging technologies so as to support sustainable development, while dealing with any negative effects and ensuring that no-one is left behind. Governments have a broad range of instruments, from regulatory measures and economic and fiscal instruments, to education and regional policies that support innovation. While encouraging change, policymakers can influence its direction and mitigate the risks of increased inequality. Governments should explore ways to make goods and services that use frontier technologies benefit vulnerable and low-income groups, including by offering services free, while extending access to digital infrastructure and skills. These efforts can be supported by the international community, which can foster an inclusive global dialogue about all aspects of fast technological change and its impact on society, including the ethical and normative dimensions. International organizations can also help establish the appropriate governance frameworks. At the same time, it will be important to have extensive social activism and grassroots innovation. All this will mean expanding capacities in technology assessment at national, regional and international levels.

1. SETTING ETHICAL FRAMEWORKS

There is the increasing concern about the ethical principles that are shaping technological development, particularly AI (See Box IV 2). Many voluntary initiatives are aiming to ensure that the processes and outcomes are fair, transparent, accountable, and inclusive. Over 160 principles, guidelines, and frameworks have been developed by academics, NGOs and industry, along with governments and supranational bodies. These are listed in Annex D.

In 2019, to contribute to the broader public debate, the United Nations, published a strategy on new technologies,[80] and established the High-level Panel on Digital Cooperation.[81] This has been a particular concern for UNESCO which in 2020 released the first draft of its Advice on the ethics of artificial intelligence, for possible adoption by UNESCO's 41st General Conference in 2021.[82] UNESCO's advisory body, the World Commission on the Ethics of Scientific Knowledge and Technology, has addressed the issue of robotics ethics.[83]

The wealth of diverse initiatives has revealed different and sometimes conflicting emphases and priorities.[84] Overall, they do not endorse one single ethical principle but generally converge around five principles: transparency, justice/fairness, non-maleficence, responsibility, and privacy. Translating these principles into policies for global governance will require cross-national harmonization while respecting cultural diversity and moral pluralism.[85]

Regarding gene editing, several prominent scientists, including some who worked on the development of the original CRISPR technology, have called for a global moratorium on heritable gene-editing until there is broad societal agreement on the use of the technology, the safety issues are addressed, and the long-term biological consequences are sufficiently understood.[86]

The European Society of Human Reproduction and Embryology and the European Society of Human Genetics have identified many societal concerns including disability rights, the undermining of reproductive autonomy, and enhanced or 'designer' babies. At the same time there are potential advantages of human gene-editing by improving health and respecting reproductive autonomy, especially of people at high genetic risk of having a child with a serious disorder.[87]

The World Health Organisation has formed an expert advisory committee on "developing global standards for governance and oversight of human genome editing" which first met in March 2019. The committee will examine the scientific, ethical, social and legal challenges and make Advices on appropriate governance mechanisms.

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Despite the different viewpoints, at least two arguments are consistent throughout.[88] First, the need for further research and a greater understanding of the risks and benefits of human germline gene-editing. Second, the need for on-going discussion involving a wide range of stakeholders regarding the potential clinical use and ethical and societal issues.

Normative and ethical considerations are also being deliberated for other frontier technologies, including synthetic biology, IoT, nanotechnology, drones, and neuro-technologies. All these discourses must include developing countries, especially the least developed countries, which may not be producing frontier technologies but will certainly be affected by them.

Box IV 2
AI as a global enterprise[*]

At a Politico event in Brussels in 2019 I was asked what kept me awake about AI if I think there are enough people worrying about the ethical issues, and my answer was diversity. I include diversity very much as part of the ethics of AI. I like to make the point that if it isn't diverse, i.e. developed by a diverse team, then it isn't ethical. It is so important that AI products and services are developed by interdisciplinary and diverse teams so that they work for the whole of society, not just a subset of it. This is particularly important in developing countries where they may not currently have many people or companies with the technical skills needed to develop AI products and services, but they will need to have people and companies who can support the deployment of AI throughout the public and private sectors. This will require diverse – in the broadest sense of the word – sets of skills to ensure the AI technology used is good for society and the development of emerging economies.

As developing countries create their own AI strategies, top of the agenda has to be skills. They need to foster AI awareness throughout the education system and attract the brightest and the best to become involved in the AI sector, both in terms of developing their own skills base of AI developers, and a skills base of policy makers, company executives, lawyers, educators etc. who can steer the adoption of AI throughout the public and private sectors and the adaptation of AI products and services into their own culture and economy to best effect. Above all they need leaders who understand the importance of AI for the future development of any country and the need for it to be managed and utilised responsibly. This has to be set in the context of the overall digital strategy for each country.

We urgently need practical tools, techniques and methodologies to enable AI companies throughout the world to develop AI in a responsible way as a matter of process, and governments to ensure, through the right mix of regulation and practical guidelines, that this is the case. This will inevitably include data curation, analysis and provenance tools to enable companies to detect data and algorithmic bias and check the veracity of data, tools for explaining the output of an AI algorithm, and tools for performing AI audits to check that algorithms are doing what the companies claim they are supposed to be doing, amongst many other things that will be required as the AI developments of today move to become a mature industrial sector. We should be putting a lot more research and innovation funding into this area as there are many problems to be solved before we can develop effective and efficient solutions that can be used to underpin government regulations.

We can also learn from what has happened in the past with the development of scientific and technological breakthroughs that can be potentially devastating if not dealt with responsibly, but have huge potential to deliver world-changing and indeed life-saving results for the common good. For example, the world has relatively successfully constrained the use of nuclear energy and biochemical agents in warfare, whilst harnessing those technologies for the good of society. We need to do the same for AI, but hopefully we can achieve global agreements in this area before a global disaster occurs rather than after. The United Nations will potentially play a very significant role here.

The United Nations can also play an important role to ensure that AI is used to support the Sustainable Development Goals throughout the world. We will see the deployment of AI being managed differently in different countries and different cultures to better meet local and regional needs. An interesting example here on a recent visit to Dubai, where they were talking about cloud seeding to induce rain – an obvious application of AI as the technology matures. If every country in the world seeks technology to disturb natural weather patterns for the local good - we may have global agreement as to its application for the common good.

As mentioned earlier, the issue of ethics and AI is really important and it is one that needs to be discussed at all levels – local, regional, national and international – but at the same time it is necessary to build AI systems in a responsible way so we can see the effects they have, both good and bad, and can use the results to develop ethical policies and frameworks for AI companies to comply with in practical ways. These should include diversity in its broadest sense, and again this is something the UN can support globally at the highest levels.

National AI strategies are really important but it is just as important that we collaborate internationally as compete. AI has the potential to solve or help manage the biggest challenges that society faces in the 21st century. If countries pool resources (data, research results, expertise etc.) they could achieve a lot more a lot faster and still enable companies to compete internationally to sell the products and services that are produced as a result. It is also important to find ways to come to agreement internationally about what are the biggest threats that AI could pose to human civilisation and seek to mitigate against these becoming a reality in a future world. It is here that the role of international organisations like the United Nations become very important.

* *The views expressed herein are those of the author and do not necessarily reflect those of the United Nations or its officials or Member States.*

Source: Contribution by Dame Wendy Hall (University of Southampton).

2. CONDUCTING TECHNOLOGY FORESIGHT AND ASSESSMENTS

Technology assessments (TAs) examine the societal effects of technologies – analysing different techno-system paths and their impacts on inclusive and sustainable development.[89] A TA should be problem oriented as well as scientific, interactive and communicative. It should help shape public and political opinion on the social aspects of science and technology, on its risks and opportunities, and it should provide effective, pragmatic and sustainable policy options.

New types of TA use broader inputs and go beyond purely technical or accounting exercises.[90] They can catalyse social, political, and inter-institutional debates on the pros, cons, and associated uncertainties across alternative directions (Box IV 3). They can involve foresight exercises bringing together key agents of change and sources of knowledge, to explore possible scenarios and develop strategic visions and intelligence to shape the future.

Technology assessment and foresight were important tools for policymaking in the 1980s and 1990s, with many countries establishing technology assessment units in the parliament to inform legislation. In the 2000s, the notion of technology assessment became somewhat out of fashion, with concerns of being dependent of political interests and power struggles.[91] But now there is an increasing interest in TA and it is crucial to revive and develop national capacities in TA and foresight so as to enable countries to identify and exploit the potential of frontier technologies for sustainable development.

Box IV 3
UNCTAD's technical assistance on technology assessment

In 2021, UNCTAD is launching the project "Technology assessment in the energy and agricultural sectors in Africa to accelerate progress on Science, Technology and Innovation." The project aims to build capacity in three selected African countries to carry out technology assessments in the energy and agricultural sectors, and to utilize technologies as catalysts for sustainable development. The technology assessment activities will focus on new and emerging technologies that have the potential to improve access to modern energy services and enhance agricultural productivity and livelihoods.

The proposed technology assessments would also consider how new technologies contribute to solving problems specific to women and girls or that affect them particularly. Through the principle of "leaving no one behind", gender considerations will inform project analysis, design, implementation and evaluation. Considering the COVID-19 pandemic, the project will also investigate how technologies applied within the agricultural and energy sectors can support improved resilience to pandemics and massive, short-term shocks, and help the beneficiary African countries build the future better.

Source: UNCTAD.

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3. SUPPORTING INCLUSIVE INNOVATION

Inclusive innovation on frontier technologies needs a supportive ecosystem. Even the most brilliant innovative or scientific mind will struggle to bring products to scale in a geographically remote area. At the same time, decades of efforts on technology innovation for development have shown the dangers of introducing technologies to resource-poor settings without meaningfully involving people in the innovation process. The emergence of India and China as major innovation players has somewhat increased the flow of relevant, innovative technologies addressing the needs of low-income populations, but usually innovation worldwide still targets the needs of the middle-classes and above.

Lower-income countries will need assistance if they are to develop the capacity for inclusive innovation. An example of an international cooperation to assist on that task is UNCTAD's programme on STI Policy Reviews, which helps developing countries strengthen their national innovation systems (see Box IV 4). STI deployment roadmaps could help stakeholders identify adapt, adopt, and deploy at scale the frontier technologies that will help them achieve the SDGs. For this purpose, the United Nations has a Global Pilot Programme on STI for SDGs Roadmaps. These roadmaps should spell out what is needed in terms of capacities and resources, as well as the various responsibilities of governments, NGOs and enterprises and potential support from bilateral and multilateral development partners.

Box IV 4
UNCTAD's STIP Reviews: Strengthening national innovation systems of developing Countries

UNCTAD's STIP Review programme aims to support the development of national productive capacity in developing countries and the achievement of the SDGs through technological development and innovation. Reviews are conceived to support STI policy-making in developing countries by assessing the effectiveness of their current STI policies and identifying priorities for action leading to sustainable development outcomes.

STIP Reviews are undertaken at the request of member States. Following an extensive review and evaluation of the country's STI actors, networks, interactions, institutions, capabilities, policies and the overall environment, which involves consultations with all the STI stakeholders, a diagnosis is established and policy options formulated and presented to the STI policymakers and then to the other national STI players.

The outcome of the analysis is documented in a STIP Review report which sets out an action plan for consideration by the Government. The STIP report is disseminated through the UNCTAD intergovernmental mechanisms, the CSTD and among national STI stakeholders through workshops and other events.

As of the end of 2020, UNCTAD had implemented 19 national STIP Reviews and had initiated reviews in two other countries. In several beneficiary countries, STIP Reviews have ignited significant renewal in STI policy, helped raise its profile in national development strategies and facilitated the inclusion of STI activities in international cooperation plans.

Source: UNCTAD.

The environment for inclusive innovation can be strengthened by other initiatives. University students and local research scientists, for example, could participate in mission-oriented research and deployment programmes, stimulated by competitions. The Rwanda Innovation Challenge,[92] the Rwanda Innovation Fund supported in part by a $30 million loan from the African Development Bank,[93] Grand Challenges Canada,[94] and USAID's Grand Challenges For Development[95] provide interesting examples of how these mission-oriented innovation programmes can be organized and administered.[96]

Major inroads have already been made in this effort by foundations like Gates, coalitions such as GAVI. There are also "open lab initiatives" such as the Tres Cantos Open Lab Foundation that allows independent researchers to access GSK R&D facilities, resources and expertise to help them advance their own research focused on medicines for endemic infectious diseases (see Box IV 5). These initiatives have incentivized pharmaceutical companies and others to take on infectious diseases that primarily affect the developing world.

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Box IV 5
Tres Cantos Open Lab Foundation

In 2001, the pharma company GSK converted one of its major laboratories in Tres Cantos, Spain, into a profit-exempt laboratory dedicated to developing drugs to treat diseases affecting primarily people in the developing countries. In 2010, the Tres Cantos Open Lab Foundation was created to allow independent researchers to access GSK R&D facilities, resources and expertise to help them advance their own research focused on medicines for endemic infectious diseases, including malaria and tuberculosis. In their turn, these researchers are encouraged to share their work with other researchers. The Foundation also provides funding to support the researchers.

The Foundation combines funding with access to state-of-the-art industrial facilities and expertise. This approach facilitates transfer and co-creation of tacit knowledge on drug discovery and pre-clinical R&D through the colocation of external researchers with GSK scientists. It also facilitates learning-by-doing by allowing access and integrating Open Lab fellows into the work in the Lab's industrial facilities.

Source: UNCTAD based on Harvard Business Review (2019a) and TCOLF (2020).

Governments can also establish centres of excellence. Modelled after the Manufacturing USA Institutes,[97] these centres would help all stakeholders identify and evaluate potential solutions for which government procurement can help build national markets.[98] Governments could, for example, contract with social enterprises to put rooftop solar and potable water kiosks in schools, health clinics, municipal buildings and other government facilities. By providing initial markets and assured revenues they can help social enterprises gain footholds in regions where they were not previously active.

International development partners could help to support these initiatives in two ways. First, foundations and bilateral donors could establish a Global Know-How Transfer Fund to help transfer successful implementation models from one country to another. Foundations and bilateral donors may also wish to establish a Deployment Support Fund to help entrepreneurs expand into new markets.[99]

Support comes from organizations such as Grand Challenges Canada,[100] USAID's Grand Challenges for Development,[101] and the National Innovation Foundation – India which specializes in grassroots innovation.[102] Innovations in Healthcare is dedicated to improving "access to affordable, quality care for people who need it most."[103] IEEE Empowering a Billion Lives focuses on developing new strategies "to scale energy access solutions 1000x".[104] Feed the Future/Partnering for Innovation[105] "builds partnerships with agribusinesses to help them sell new products and services to smallholder farmers." Mission Innovation is "working to accelerate clean energy innovation."[106]

Just as important as developing these technologies is finding ways to deploy them at scale on a financially sustainable basis. Global Good, which is developing an extensive pipeline of development solutions for Medical Cold Chain Equipment, is funded by the Bill & Melinda Gates Foundation and aims to "direct technology to the poorest people on Earth—to transform the lives of people who need their lives transformed."[107] Also funded by the Gates foundation is Global Health Technologies – a coalition of organizations and businesses to accelerate the creation of new drugs, vaccines, diagnostics, and other tools.[108]

4. DEPLOYING AT SCALE

Pilot solutions that work well in one place often need adapting to work elsewhere in the same province or country, not to mention in neighbouring or more distant countries. If this does not happen, the result is a proliferation of pilot projects. Between the piloting and scaling phases proven technologies can get stuck in a "stagnation chasm."[109] To avoid this, governments and companies can consider the following suggestions.

Be guided by a vision – Organizations deploying technology should start with an ambitious vision, such as to provide drinking water to at least 100,000,000 people in the next five years. They then need

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to determine how to achieve it with strategies for mobilizing the required technical, financial, human capital, partnership, political and other essential resources, and then develop a plan for scaling up.[110]

Talk to users – Parachuting top-down solutions into unsuspecting communities or to potential customers is a recipe for failure.[111] This is true irrespective of whether the potential customer is a sophisticated technology firm in Silicon Valley or a smallholder, subsistence farmer in Africa. To launch a successful deployment programme, customers need to participate in both the product development and product marketing phases because, successful deployment programmes are a function of "culture, values, ethics, trust, leadership, history, politics," as well as superstition, local customs, and social structures.[112] If the scientific community ignores non-science factors, deployment will founder irrespective of the technical parameters.

Pass the baton – Harnessing frontier technology for the SDGs, is akin to a relay race in which the baton must be passed smoothly, quickly, and efficiently from the scientists and engineers who develop new technological solutions to a completely different group of individuals – primarily non-scientists – who will take the lead in deploying these innovations at scale.

Generate incomes – Income generation should not be viewed as a distraction or minor add-on to existing deployment programmes but rather as an indispensable component of sustainable deployment. No matter how heavily subsidized the technology, people will not continue to use it if they cannot afford it. The solution, therefore, is to use technology that will generate more income for households and communities by providing better access to more remunerative formal markets, especially in rural areas. Similarly, they will need to extend credit, training and support that will enable smallholder farmers to fit into complex value chains. For example, Twiga is using digital technology to link Nigerian smallholder farmers to more lucrative formal urban commercial markets,[113] while in India, Promethean Power Systems[114] is deploying off-grid, non-diesel milk chillers to link small dairy farmers with formal food processing enterprises.

The solution is to use technology that will generate more income for households and communities by providing better access to more remunerative formal markets, especially in rural areas.

5. IMPROVING PUBLIC SERVICES

New technologies can also be used to decrease inequalities by improving services provided by the public sector.[115] This will mean (1) investing in the capacity of civil servants, (2) facilitating the free flow of information, (3) working together to solve problems, (4) using rules to support the innovation process.[116]

An important principle is that government services should not restrict access to those who are willing to use the new technologies. In 2019, 3.6 billion people, almost half of the world's population, did not have access to the Internet.[117] There is a clear digital divide between developed regions, where 87 per cent of the population are using the Internet, and the least developed countries, where the proportion is only 19 per cent.

The government's procurement power can create markets for technologies that would make lives better for poor households. Governments can also help absorb frontier technologies by investing in strengthening the capacity of the public service workforce. For example, in many countries, healthcare workers are primarily public employees and the whole health system could benefit from their increasing capacity on the use of new technologies in healthcare.

Another procurement option is for the management of foreign trade. In 1981 UNCTAD established the Automated System for Customs Data (ASYCUDA) programme to help developing countries modernize their customs services and automate the customs clearance process. ASYCUDA covers most foreign trade procedures, and is an example of an effective programme that has applied new technologies in public sector services while helping governments make the required institutional changes and create environments for the successful deployment of these technologies (see Box IV 6).

Another area where public sector investment can affect inequalities is through educational innovation.[118] The systems that have innovated the most tend to produce the most equitable student learning outcomes, as in Indonesia, for example, and the Republic of Korea.[119]

Box IV 6
UNCTAD's Automated System for Customs Data – ASYCUDA

The Automated System for Customs Data (ASYCUDA) programme was established by UNCTAD in 1981 to support the efforts of developing countries to modernize their Customs Services and to automate customs clearance processes. Since then, the ASYCUDA programme has become the leading Customs Reform Programme and the ASYCUDA Integrated Customs Information System, developed by UNCTAD, is among the world's most comprehensive Customs automation systems. ASYCUDA combines state-of-the-art information technology and proven field experience.

ASYCUDA has become UNCTAD's largest technical assistance programme with more than 100 user countries, including 41 African countries, 39 Least Developed Countries, 34 Small Island Developing States and 21 Landlocked Developing Countries.

ASYCUDA projects, comprise expertise, technical assistance activities, implementation of the ASYCUDA system and corresponding training. They aim to speed up the customs clearance process while enforcing security, through the introduction of computerization, along with simplifying procedures and thus minimizing administrative costs.

During the last few years, at the request of member countries, the ASYCUDA programme has been broadened to include automating trade facilitation procedures using frontier technologies such as AI and blockchain.

Countries interested in implementing the system, increasingly fund their own ASYCUDA projects. For those countries that do not have a budget allocated for that purpose the ASYCUDA programme has been able to assist countries in securing funds for implementation. Donors include the African Development Bank, Asian Development Bank, COMESA, Enhanced Integrated Framework, EU, German Corporation for International Cooperation, Southern African Development Community, TradeMark East Africa, and the World Bank.

Source: UNCTAD.

6. BRIDGING DIGITAL DIVIDES

Over the past two decades, national governments and the international community have aimed to extend digital services across the world. This has had some success. At the beginning of this century, only a privileged minority had Internet access, but by 2018, for the first time in history half of the people on the planet were connected, and progress was continuing across all regions.[120] A pivotal moment was the World Summit on the Information Society (WSIS) held in 2003 and 2005 (Box IV 7) which has been followed up by various stakeholders, including the United Nations Commission on Science and Technology for Development, for which UNCTAD serves as the secretariat. There is an annual WSIS Forum and the WSIS outcomes are due to be reviewed again by the United Nations General Assembly's WSIS+20 review in 2025.

Box IV 7
International cooperation for bridging the digital divides

The UN Commission on Science and Technology for Development (CSTD) acts as the focal point for the United Nations system-wide follow up to the World Summit on the Information Society (WSIS), with its core principles and action lines in terms of digital cooperation agreed by the international community. The CSTD is also the United Nations inter-governmental process with a mandate and expertise to articulate the critical role of STI as enablers of the SDGs and to inform and advise the United Nations General Assembly, the ECOSOC, the HLPF and other relevant forums.

The United Nations Group on the Information Society, currently chaired by UNCTAD, is an inter-agency mechanism to coordinate the implementation of WSIS outcomes throughout the United Nations system, which meets annually during the WSIS Forum. To support this process, the WSIS stocktaking platform, maintained by ITU, provides information on more than 12,000 ICT and development activities undertaken by diverse stakeholders across

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different WSIS action lines. The International Chamber of Commerce coordinates WSIS-related activities through its Business Action to Support the Information Society initiative and contributes to international discussions including the WSIS Forum. ITU also works with governments to support infrastructure deployment, including the development of national broadband strategies and communications regulation.

International cooperation has also focused on addressing new gaps that emerged in terms of broadband connections. In this regard, the Broadband Commission for Sustainable Development was launched in 2010 by ITU and UNESCO to boost the importance of broadband on the international policy agenda and expand broadband access in every country.

Another essential mechanism is the Internet Governance Forum (IGF), launched in 2006, which provides a platform for exchanging information and good practices. More recently, the High-level Panel on Digital Cooperation was established in 2018 to consider collaboration on addressing the social, ethical, legal and economic impact of digital technologies.

UNCTAD's Rapid eTrade Readiness Assessment programme provides beneficiary countries with a quick assessment of current opportunities and challenges in eCommerce, as well as the main priorities ahead in harnessing e-commerce for development.

Source: UNCTAD.

ICT infrastructure continues to improve, especially in the developed countries, as companies implement 5G networks. To ensure that developing countries are also an important part of this, the World Bank and other international financial institutions provide support for infrastructure projects. The Bank has committed $25 billion to connect all African Governments, businesses and citizens to high-speed broadband by 2030 – which would cover one-quarter of the total cost requirements. The World Bank Digital Development Partnership provides a platform for digital innovation and development financing.

Special attention is needed for underserved areas that are not commercially viable for private companies. Here, governments can include specific network rollout obligations as conditions for granting licenses. They can also encourage network infrastructure sharing and mutualization among operators to reduce costs. They can also share the costs of some services through public-private partnerships.

A common tool is the Universal Service Fund (USF)[121] which collects funds from telecommunication operators as subsidies that can be used for private companies to extend ICT infrastructure and operate services in underserved areas. However, the experiences with USFs in over 70 countries have been mixed. Frequently there have been failures in design, with a lack of political independence and problems with training, education and maintenance.[122] On the other hand, successful USFs have been able to work on these issues while maintaining a high degree of transparency.[123] USFs can also finance terminal and connecting equipment. Although the price of these devices has constantly been decreasing, their cost is still a significant barrier. Governments may consider various forms of subsidy both for devices and the costs of connection.

Bridging digital divides will also require basic literacy and numeracy skills. In the first decade of this century some training was available in local ITC community centres. The widespread use of mobile phones has reduced the need for places to connect, but it is still important to raise awareness of the benefits of being connected (Box IV 8). This would offer opportunities for public-private partnerships in which governments raise levels of skill.

Governments that want to improve digital skills will need to do so in an inclusive manner with regard to the elderly, people with disabilities and other marginalized groups. In Singapore, for example, the Government is providing courses on basic digital skills for senior citizens,[124] while in the United Kingdom there are now some digital drop-in services.[125] Policymakers can also support social enterprises that provide training on digital skills to unemployed and underqualified people.[126]

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Box IV 8
Policies and civil society actions for universal Internet access

Many of the frontier technologies are directly or indirectly dependent on Internet infrastructure. While we have made progress regarding solving the digital divide, new divides seem to be at the horizon. Indeed, many types of technologies require large amounts of data and/or low latency capabilities, and basic connectivity is no longer enough. In this regard, the Alliance for Affordable Internet (A4AI), a global coalition to bring down the cost of Internet access in low- and middle-income countries, is advocating for a meaningful connectivity (MC) target, a tool to raise the bar for internet access and set more ambitious policy goals for digital development. The MC sets these minimum thresholds across the four dimensions of internet access that matter most to users, according to the following (A4AI, 2020a):

- Regular internet use - minimum threshold: daily use,
- An appropriate device - minimum threshold: access to a smartphone,
- Enough data - minimum threshold: an unlimited broadband connection at home or a place of work or study,
- A fast connection - minimum threshold: 4G mobile connectivity.

There is increasing awareness of the need to strengthen Internet infrastructure, and this means not only thinking about policies in the "last mile" but also policies related to parts of the ecosystem that are less visible and/or known, such as supporting digital skills and content development. Many governments have been creative in developing initiatives focused on solving connectivity gaps, and many of these are the result of innovative approaches to universal access policy. Some successful initiatives related to universal service and access funds (USF) are briefly described below:

- In Malaysia, the government used its USF and its national broadband plan to increase broadband availability and implement supply side interventions such as access pricing regulation. The latter resulted in a 40 per cent price drop for 1 Gbps and only a few months after the policy was implemented in 2018 (A4AI, 2020b);
- In Costa Rica, the government launched in 2015 a country wide policy (CR Digital) with an ambitious goal of connecting the country within two years. While this was not achieved, the country was able to use the USF to partially subsidize Internet access as well as ICT equipment, bringing over 40,000 families online (A4AI, 2020c);
- In Pakistan, which has a market approach to telecommunication infrastructure regulation, the USF was established in 2006. Besides having increased the level of penetration and access to the Internet, the USAF was also used to finance contractors to facilitate people's access to telemedicine, e-learning, and e-government at telecentres, since digital literacy is still a barrier to many (A4AI, 2020d);
- In Rwanda, the USF resources, which are managed by the regulator, Rwanda Utilities Regulatory Authority (RURA), are used to provide connectivity to all districts in the country, including through telecentres, and public and private universities. Affordability has improved dramatically, and while in 2015, the price of 1GB of data was 20 per cent of the average Rwandan's monthly income, the same data package costs around 3.4 per cent today (A4AI, 2020e).

Establishing clear targets to ensure timely disbursement of USF funds is as crucial as dedicating part of these funds to projects focused on women's access and use, especially as the digital gender gaps continue to hinder development opportunities. Since 2018 the Web Foundation, A4AI and UN Women have been advocating for USF to dedicate a minimum of 50 per cent of their unused funds to support women and girls centred projects. They further recommended that (i) project design and implementation should be more gender-responsive; (ii) transparency of fund financing, disbursements and operations should be increased; and (iii) USF's governance aspects should be taken into consideration, with increased awareness of gender targets and concerns (World Wide Web Foundation et al., 2018).

These are only some examples of how governments are addressing universal access provision, but much more remains to be done. A necessary step is designing policies that focus on affordable and meaningful connectivity that is truly enabling for users. Working towards bridging these gaps sooner rather than later, would help avoiding future gaps related to frontier technologies.

Source: Contribution by the Alliance for Affordable Internet (A4AI).

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Beyond digital literacy, people who want to go further and adapt frontier technologies for their own purposes will need more specialized training in statistics, for example, programming languages and big data analytics. And at the more advanced level, for creating new technologies they will need sophisticated programming skills and knowledge of complex algorithms, including those used in machine learning.

Regional economic development initiatives often build infrastructure in areas of a country that are being left behind. More than 30 countries report such initiatives. The Republic of Korea is using R&D Special Districts and efforts to strengthen industrial clusters as part of its regional innovation effort.[127] Finland is synchronizing its national and regional innovation strategies.[128] Mexico has an Institutional Fund for Regional Development of Science, Technology, and Innovation Activities.[129]

7. INVESTING IN STI SKILLS

Digital capabilities are increasingly important, not only for jobs, but also for social and civic participation in current and future societies. People will not just need basic technical skills but should also be able understand media, be able to search for information, be critical about what is retrieved, and communicate through a variety of digital tools and applications.[130] Many frontier technologies are designed to be used in countries with extensive infrastructure and abundant natural and social resources. Developing countries will therefore need sufficient technical skills to introduce modifications.[131]

Skills can be at four levels of engagement:[132]

1. Adoption – basic education, literacy and familiarity with technology devices
2. Basic use – understanding of new technologies, knowledge of digital rights, privacy and security, ability to use digital technologies to collaborate and create
3. Creative use and adaptation – basic computing skills and familiarity with algorithms
4. Creation of new technologies – sophisticated programming skills and knowledge of complex algorithms.

Countries where technology development remains in its early stages need basic technical and generic skills. On the other hand, in countries where economic growth is already driven by manufacturing, the workforce must have specialized skills in robotics, automation and the IoT. In any case, it is critical to recognize that a lot of this learning happens on the job and through interacting with the technology. Building capacity in these skills are part of a broader process to build and strengthen innovation systems that develop productive capacities for industry, manufacturing, services, and higher value-added activities and exports.

Most government programmes that support innovation are directed towards human resources in educational institutions.[133] Direct support goes to established researchers, post-doctoral researchers, PhD students, undergraduate, masters, and secondary school students, and teachers. Many of these programmes address horizontal inequalities; for example, in the policy database maintained by the EU and OECD more than 35 countries list national initiatives on gender in science and engineering.[134] There are also programmes for other disadvantaged and excluded groups, including those focused on assistive technologies,[135] indigenous groups,[136] displaced populations,[137] and the elderly.[138]

8. SUPPORTING ACTIVE SOCIAL CITIZENS

Technologies often amplify human capacities and magnify existing social forces, through institutions, networks and social norms, but the impacts will ultimately depend on how societies respond, and in particular on the extent of social citizen activism, which can help steer technological development towards sustainable outcomes. Networks of activists, academics, and practitioners can experiment

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with alternative possibilities based on local knowledge and driven by environmental and social needs.[139]

An example of contemporary grassroots effort is the maker movement, which has driven informal experimentation in microelectronics, software, robotics, and digital fabrication. Through hackerspaces, fab labs, and makerspaces, the maker movement encourages open-source technologies, free information, an economy of sharing and sustainable technologies. The One Million Cisterns Project, for example, was conceived by a network of over 700 NGOs, farmers' groups, and civil society organizations, and provided water cisterns in a large semi-arid region of Northeast Brazil.[140] The technology was built by farmers and masons and was used to foster community-based learning and empowerment.

Social citizen activism and grassroots innovation can be supported through initiatives that provide funding, link grassroots innovation to existing R&D institutions, and support international networking for increased visibility and legitimacy.[141]

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[140] https://dry-net.org/initiatives/one-million-cisterns-for-water-harvesting-in-north-east-brazil/, (accessed on 25 August 2019).

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CHAPTER V

PREPARING FOR THE FUTURE

Technological progress is essential for sustainable development but can also perpetuate inequalities or create new ones.

The task for governments is thus to maximise the potential benefits, while mitigating harmful outcomes.

Countries at all stages of development should promote the use, adoption and adaptation of frontier technologies, preparing people and firms for what lies ahead.

The basic requirements are an effective national governance to guide technological change, international cooperation for strengthening a global framework for STI for development, and vigorous citizen activism to keep the SDGs as central guiding principles.

Key policy areas need special attention:

1) Policy should direct technological change towards meeting societal needs and reducing inequalities

2) Developing countries should adopt frontier technologies while continuing to diversify their production bases by mastering existing technologies

3) Strengthen social protection systems to provide safety nets for workers who may lose their livelihoods

International cooperation should focus on:

1) Build stronger national capacities in STI

2) Smooth technology transfer

3) Increase women's participation

4) Improve foresight and technological assessment

5) Promote inclusive debate

Technological progress is essential for sustainable development, but can also perpetuate inequalities or create new ones, either by limiting access to more privileged groups and affluent countries, or through built-in biases or unintended consequences. The task for governments is to maximise the potential offered by frontier technologies, while also mitigating harmful outcomes, and ensuring access for all. Countries at all stages of development need to promote the use, adoption and adaptation of frontier technologies, preparing people and firms for the new possibilities ahead.

A. KEY REQUIREMENTS FOR EQUITABLE OUTCOMES

The previous chapters have indicated some of the basic requirements. First, effective national governance to guide technological change. Second, international cooperation for supporting developing countries and strengthening a global framework for STI for development. Third, vigorous citizen activism that can raise awareness and create a critical mass to ensures that society and institutions steer technological change towards sustainable and inclusive development.

1. National governance

The world already has a broad framework for giving direction to technological progress. Innovation and choice should be guided by the Sustainable Development Goals. In practice, however, left to their own devices, private firms will not make investments primarily for the public good. If private sector options and choices are to be guided by the SDGS towards sustainable transformations then the state should have “the vision, the mission and the plan” to create and shape the market for these inclusive and sustainable innovations.[1] Governments will also need to make investments in human and physical resources. Some existing funds can be reallocated to better uses, such as research and education, but governments will also have to mobilize new resources through changes in taxation.[2]

2. International cooperation

In parallel it will be important to revitalize international governance and cooperation. The global community should fully embrace STI for sustainable development – promoting the use, adoption and adaptation of frontier technologies while extending access far and wide and ensuring that no one is left behind. Most developing countries will not have sufficient resources on their own. They will need international cooperation to help them align their STI goals with national development objectives and the SDGs, formulate coherent STI policies, and design appropriate policy instruments.

Governments should also work together more closely to build an international institutional framework that embraces countries at all stages of technological development. This is especially important for developing countries which have distinct interests and priorities and need to be represented on the global stage. Individual governments and firms, and other stakeholders may resolve to make technology work for the public good but nothing can take the place of truly international cooperation.

3. Social activism

Accelerating reform of institutions will require vigorous social activism, with people and organizations working together to identify mismatches between technological innovation and societal responses. Laws, regulations and behaviour developed for previous technologies are usually ill-suited for radical new challenges. Due to both societal and institutional inertia these changes have been slower and have lagged behind technological transformation. Indeed, for previous technological revolutions, completing these changes has taken one or two generations.[3] Keeping the SDGs as central guiding principles requires proactive participation of all stakeholders including civil society organizations. It will take time, but the combined efforts of civil society groups can lead to changes in regulations and laws and eventually trigger changes in user and consumer behaviour so as to align frontier technologies with societal goals.

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B. KEY POLICY AREAS

Previous chapters provide examples of existing policies, strategies and institutions that can foster frontier technologies and address some of their unintended consequences. This section provides an overview of key policy areas for developing countries. These should be addressed through a whole-of-government approach – with close policy coordination and multi-stakeholder participation – and with bold ambition that recognizes the potential transformative power of frontier technologies and the new wave of technological change to move the world towards an inclusive and sustainable future.

1. Guiding innovation towards reducing inequalities

Governments should steer technological change towards societal needs, while also taking measures to deal with unintended consequences and mitigate the risks of increased inequality. For this they can draw from a broad range of instruments including regulatory measures and economic and fiscal instruments, as well as smarter policies on trade, investment, industry, education and innovation. Governments should also ensure that vulnerable and low-income groups have access to valuable and socially relevant new goods and services enabled by frontier technologies, some of which can be subsidized or provided free as public services.

Set strategic directions using the SDGs

The SDGs should serve as the basis for collective priorities – social, economic and environmental. These should drive national plans for research and innovation and for the use, adoption and adaptation of frontier technologies – aiming to reduce inequality between social groups, individuals, regions and countries. STI policy instruments should cover such areas as: funding for research and development and innovation; tax incentives for adopting and adapting technology; public procurement to create or stimulate markets; creating clusters, industrial zones and technology parks; and providing training and business advisory services.

Public policy should also direct the use of critical new frontier technologies to sectors that might otherwise be slow to exploit them – including parts of agriculture, healthcare, energy and transport. For example, there are now emerging best practices on how to integrate general-purpose technological knowledge to tackle climate change. Similar attention needs to be given to the opportunities offered for the SDGs by other frontier technologies.

Extend frontier technologies to the poor

People at the bottom of the socio-economic pyramid should not fall further behind. Wide-scale deployment of the associated products and services will not happen automatically, particularly in low-income and vulnerable settings. Extending the benefits of frontier technologies to the poor will require energetic public policy – devising plans, raising awareness, and creating incentives within a national innovation system, while also encouraging investment and community participation. Moreover, these solutions should generate incomes. The poor should not be limited to being users or beneficiaries, they should also be able to take the opportunities provided by the frontier technologies to boost their incomes and improve their livelihoods.

Use frontier technologies in the public sector

A part of this will be achieved through smart procurement. The government should use its buying power to create markets for technologies that will stimulate economic development while also making lives better for poor households. Based on procurement, governments should steadily embed frontier technologies in services such as health and education. This will require careful design, paying close attention to potential changes in vertical and horizontal inequalities.

Support inclusive innovation systems

Technology use tends to be shaped by existing social and economic inequalities, and in their turn, these technologies can perpetuate and exacerbate these inequalities. Therefore, technological applications on their own are unlikely to cause large-scale social changes towards equitable outcomes. In this context, social citizen activism and grass roots innovation play an essential role in directing innovation and knowledge diffusion to promote social inclusion. Governments can in turn respond to alternative models of technological change by facilitating funding, linking these models to existing R&D institutions, and increasing their visibility through international networking.

2. Adopting frontier technologies while mastering existing technologies

To catch up and forge ahead, developing countries should adopt frontier technologies while continuing to diversify their production bases by mastering many existing technologies. To ensure that they benefit from the window of opportunity offered by the new wave of technologies, they should keep both targets in sight. This will mean strengthening their innovation systems, while aligning STI and industrial policies, building basic digital skills, and closing gaps in ICT infrastructure.

Strengthen national innovation systems

In many developing countries, innovation systems tend to be weak and prone to systemic failures and structural deficiencies. Governments should strengthen their national innovation systems, drawing in a wide range of actors who can help build synergies between STI and other economic policies (e.g. industrial, trade, fiscal, monetary and educational policies). In this regard, UNCTAD has written extensively on innovation systems and how to build an enabling STI environment.[4] UNCTAD's STI Policy Reviews can also help governments integrate STI policies into their national development strategies while working towards the SDGs.

Align STI and industrial policy

New technologies can re-invigorate traditional production sectors and speed up industrialization and economic structural transformation. It is essential therefore to align policies for STI and for industry. Together these should draw firms into the core of frontier technology development, so as to achieve fast increases in labour productivity. This would enable traditional production sectors to benefit from multiple channels of technology diffusion, including foreign direct investment, trade, intellectual property rights, patents and the exchange of knowledge and know-how. Countries should foster these linkages by supporting collaborative research and strengthening business partnerships.

Rapid exchanges of information can fuel innovation, giving firms a better sense of consumer needs, technological possibilities, and opportunities for increasing competitiveness. Some collaborative innovation will occur spontaneously, but other links, especially those related to social and environmental challenges, will need to be deliberately forged by governments or organizations from civil society.[5]

An important part of STI policy is the establishment of science parks, incubators, accelerators, and innovation labs.[6] These enable scientists, engineers and entrepreneurs to work in clusters to facilitate experimentation and enable faster development. Just as important, STI policy should promote the scaling up and dissemination of successful innovations that emerge from these hubs – encouraging academia and civil society to engage with the private sector to deploy new products in marginalized and vulnerable communities.

Develop digital skills

Policymakers also need to consider how people can acquire the necessary digital skills and competencies to adopt and adapt frontier technologies into countries' existing production bases. Digital competencies include technical skills, but also generic and complementary skills. Skills are needed at all levels from the basic ability to adopt new applications and products, to the higher-level programming and other skills to adapt imported technologies and create new ones.[7] Education and training programmes that focus on digital skills for all should be inclusive and accessible to everyone. Skills learning also happens through learning-by-doing and on-the-job training. The competencies needed will vary across sectors, countries and levels of industrial development. Digital policies should be calibrated according to countries' readiness to engage and benefit from the digital economy.

From the outset all these training opportunities should involve women. Everyone should be aware of the potential impacts of technologies on gender disparities, as well as of women's specific needs, and the critical contribution that they can make. Governments should facilitate women's access to technology, ensuring that they participate in setting priorities, shaping policy decisions and creating research and development agendas.

Connect everyone focusing on the furthest behind

All these policies will demand much greater digitalization and connectivity. Country-wide access to electricity and to ICT should aim to bridge gender, generational and digital divides. Through inclusive National Digital Agendas countries can focus on the furthest behind, leveraging ICT infrastructure and improved Internet access through fixed or mobile broadband.

Reaching remote areas and vulnerable groups may not be viable for the private sector, so governments will also need to consider incentives and subsidies – not just for internet access but also for providing the devices through which people connect to the network. Although the cost of these devices consistently falls over time, it is still a significant barrier for many of the poorest people.

3. Mitigating risks

There is always the risk that rapid technological change will cause harm or perpetuate or accentuate inequalities. Governments should strengthen social protection systems to provide safety nets for workers who may lose their livelihoods. They should also enable these workers to move to new jobs and economic activities by matching their skills to future needs, reforming education, and training systems, and promoting lifelong learning.

Both companies and regulators need to be vigilant to ensure that technologies using AI do not incorporate or learn social biases and forms of discrimination that can further disadvantage vulnerable groups.

Strengthen social protection

During potential labour market disruptions, workers should be able to rely on strong systems of social protection. Other options include universal basic income schemes. Several redistribution policies have been proposed to generate the additional revenue required, including by taxing capital, robots or other technologies. Evidence on the impact of these policies, especially universal basic income schemes, remains scarce, and policy experimentation is needed.

Ease workforce transitions

All over the world, countries are facing up to the needs for lifelong learning. Workers may need to change careers or skillsets several times through their working lives. The necessary training and re-training are increasingly seen as a joint responsibility of governments, employers and workers. Governments may also support workers who need to change jobs by combining skills development with personal counselling and improved job matching, and placement services. The youngest workers can benefit from apprenticeship programmes combining work- and school-based learning that can smooth the transition from school to work. There is also a role for stronger labour unions to take up workers' legitimate concerns about the implications of rapid technological change for their jobs.

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Anticipate the future

If societies are to plan for technological change, policymakers will need to consider the potentially disruptive effects for years or even decades ahead. This will require strategic vision and intelligence in the form of 'technological foresight and assessment' developed in conjunction with key agents of change and sources of knowledge. The evidence is needed to support policy and implementation, for example combining methodologies and data for technological, economic, social and environmental impacts. Such assessments help to elicit knowledge from a variety of actors about the industrial growth areas that match a country's strengths to commercial opportunities.

C. PRIORITIES FOR INTERNATIONAL COOPERATION

Achieving the 2030 Agenda for Sustainable Development will mean using all available tools to harness rapid technological change. Most of the necessary resources will come from national budgets, but many governments should also be able to rely on technical and financial support through international cooperation and official development assistance (ODA). In particular this will be needed to:

1. Build stronger national capacities in STI

The international community should give priority in its support to developing countries to build their technological and innovation capacities. In this regard, UNCTAD provides support for governments that wish to integrate STI policies into their national development strategies. Technical cooperation delivered through ODA is also important; this will mean increasing the relatively small amounts of ODA directed to STI in the least developed countries. Voluntary contributions are also invited to support capacity building in STI for SDGs in developing countries, and in particular the efforts in this area by UNCTAD and other agencies participating in the IATT of the Technology Facilitation Mechanism.[8]

2. Smooth technology transfer

The international community should help developing countries close technology gaps by facilitating technology transfer and by translating technologies into locally relevant products and services. Part of this will involve liberalizing access to trade and to technologies covered by intellectual property rights. Several reforms of the global IP regime are needed to strike the delicate balance between the advantages and costs of IP rights for developing countries to get frontier technologies, including broader room for compulsory licensing, strengthening patent standards of novelty, and limiting the length of patent protection. This is a rapidly changing environment with increasing digitalization and connectivity creating new risks and challenges, so more research will always be needed on the best forms of technology transfer. One option is to offer free online access to information on patent-free technologies that are readily available for firms in developing countries.

3. Increase women's participation in STEM

The international community should encourage girls and women to study and seek employment in science, technology, engineering and mathematics (STEM) fields, which have driven the rapid development of frontier technologies. At present these subjects are typically dominated by men. If women are to play their full part in frontier technologies, governments and international organizations will need to encourage girls and women to study these subjects and enter corresponding professions. Women should have full access to all forms of technology and be able to help set priorities, participate in decision making and shape research and development agendas. Overall, governments and the international community need a much better understanding of the gender impact of technological change.

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4. Improve foresight and technological assessment

The international community should help countries undertake strategic 'foresight and technological assessment' initiatives to better understand the socio-economic and environmental implications of new and innovative technologies. Foresight and technological assessments help to identify the risks and benefits of technologies and the policy options for steering innovation so as to leave no one behind.

5. Promote inclusive debate

Most developing countries, especially the least developed countries, are not engaged in development of frontier technologies. Nevertheless, they need to be part of the international debates on how such technologies affect citizens' rights, privacy, data ownership and online security – and especially on how they can promote the SDGs. Their concerns need to be reflected in normative frameworks and regulatory regimes on data collection, use and access, and for data privacy and security – balancing individual and collective rights, while allowing private sector innovation.

For this purpose, the United Nations offers an impartial and trusted platform where the international community can deliberate these contentious issues. Two existing mechanisms that have brought frontier technologies and sustainable development to the forefront of the global debate are the United Nations Commission on Science and Technology for Development and the Technology Facilitation Mechanism created by the 2030 Agenda on Sustainable Development.

D. CONCLUSIONS

Whole economies and societies are being reshaped by rapid technological change. As with earlier waves of technological revolution, the full picture will be slow to emerge. But it is safe to say that the long-term changes will be more far-reaching than we imagine – along all dimensions of development. To address these, governments and the other development actors will need to prepare fast.

Developing countries, particularly the least developed countries, cannot afford to miss this new wave of rapid technological change. Governments cannot know how technologies will develop but they can help shape the paths that such technologies take in their own economies and societies.

Each country will need STI policies appropriate to its stage of development. For some this will mean promoting frontier technologies while renewing efforts to take full advantage of existing technologies to diversify their economies and upgrade traditional sectors such as agriculture. Others can engage more deeply with the development of frontier technologies. But all countries need to prepare people and firms for a period of rapid change. For developing countries, success in the twenty-first century will require a balanced approach – building a robust industrial base and promoting frontier technologies that will help deliver the 2030 Agenda and its global vision of people-centred, inclusive, and sustainable societies.

1 Mazzucato, 2015
2 Banerjee and Duflo, 2019
3 Perez, 2002, 2010
4 UNCTAD, 2018a, 2019e
5 UNCTAD, 2018a
6 UNCTAD, 2018a, 2019a
7 Dimaggio et al., 2004
8 https://sustainabledevelopment.un.org/tfm

ANNEX A
CONCEPTUAL FRAMEWORK

ANNEX B
FRONTIER TECHNOLOGY TRENDS

ANNEX C
HOW TECHNOLOGIES AFFECT INEQUALITIES IN THE USER’S PERSPECTIVE

ANNEX D
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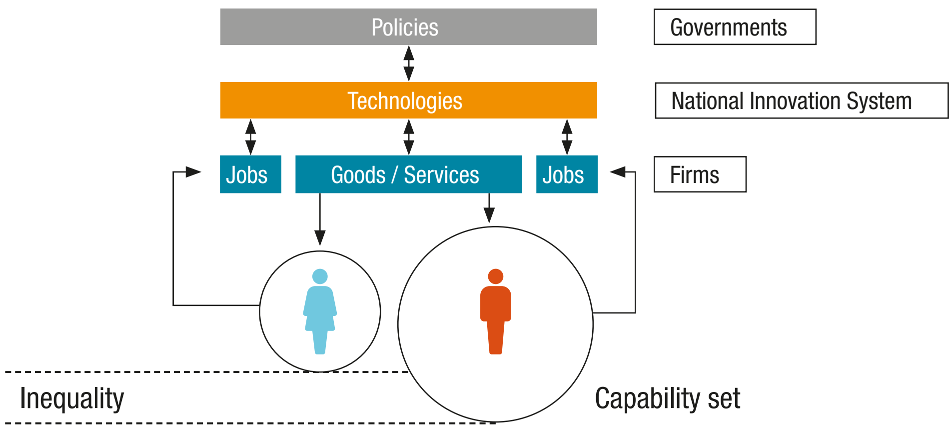
ANNEX A. CONCEPTUAL FRAMEWORK

This report uses a conceptual framework for linking technologies to inequalities (Figure 01). People's well-being is a central part of this framework because inequality is ultimately felt at a personal level. Even when dealing with divergences at aggregate levels such as countries, regions, sectors, firms and social groups, the analysis focuses on how inequality operates between people. As per the 'capability' approach developed by the economist Amartya Sen, individual well-being relates to the real opportunities that people have to do and be what they have reason to value – their "capabilities". These include being able to avoid such deprivations as premature death, preventable illnesses, hunger and undernourishment, as well as having the necessary skills and education to engage in productive work, enjoy political participation, be part of a community, and be respected. At the individual level, development is the expansion of the set of capabilities that a person has, while poverty is the deprivation of capabilities.[1] Inequalities are the manifestation of the disparities in the set of capabilities that people have.

Goods and services (provided by nature, charity, governments or markets) are the means necessary for expanding people's well-being. For example, a mobile phone device combined with a mobile phone service is the means to instantaneously communicate with people in other places while moving around a wide geographic area, which enables the capability to communicate more freely. But the relation between goods and services and the capability set is influenced by the individual, social and environmental context. This affects how a person can convert goods and services into capabilities.[2] For example, if a person has a disability that prevents her from hearing someone over the phone, or if the person lives in a mountainous area where the mobile service is not reliable, or if the person is not allowed to use a mobile phone for socially-imposed reasons, then the mobile phone will be of limited use in enabling the functioning of freer communication. The government provides some of the goods and services as public goods, such as national security, street lighting, flood control systems, epidemic control, and so on. Others are provided privately but with characteristics of public goods such as broadcast radio and television, or other sorts of information goods and knowledge. Still others are freely provided by nature, such as solar energy, clean air, water and biodiversity. However, a considerable share of goods and services is not freely distributed in the economy through public goods, charity or some system of automatic sharing. Most goods and services have to be bought in the market. From the vantage point of the person, what is important is not the supply of goods and services in the economy but the set of goods and services over which the person can establish ownership and command.[3]

Figure 01
Conceptual framework: Technologies affect inequalities through jobs, and goods and services.



Source: UNCTAD.

The entitlements that a person has over goods and services are very much determined by how he or she makes a living. In turn, how a person makes a living depends on two factors. First, the ownership of productive resources, such as her own knowledge and labour-power, as well as capital such as a productive plot of land or livestock. Second, the production possibilities that exist in the economy. In other words, a person may acquire the ability to buy goods and services by getting a wage income or by organizing productive factors held by her or others, but this will depend on the employment and entrepreneurial opportunities, which rely on the production possibilities of the local economy.

This is where technologies come in: available technologies determine the production possibilities. These technologies can be either capital-embodied technologies, such as machines and infrastructure, or labour-embodied technologies, such as procedures followed by workers to produce goods and services, or business models and management practices.[4] Therefore, the complete set of technologies in the country determines the country's productive capacity. Some technologies are required by many economic activities; clear examples being ICT infrastructure, the power grid or transport infrastructures such as roads, ports, airports or railways. The combination of the different technologies results in distinct economic activities, represented by the goods and services they produce.[5] This report follows UNCTAD's tradition and theoretical foundation that understands economic development as a process of structural transformation.[6] This may be hindered by factors that limit the capacity and willingness of private firms in developing countries to innovate and upgrade their productive and technological capacities.

A national system of innovation (NIS) is the broad network of actors required to develop new technologies and combine them with existing ones into new products and processes of production. Private firms have a unique role in technological change, being the place where new technologies are usually conceived, developed, and eventually commercialized, but they typically do not innovate in isolation. Firms are part of a system which also comprises universities, research centres, civil society organizations, financial institutions and governments, among others, whose interactions allow the flow of ideas and resources required for innovations. The market provides firms with incentives to develop new technologies, through either new processes or new products. The government has the primary responsibility for policies, rules and regulations that provide an environment that can enable technological change.

Based on this framework, technologies affect inequalities through jobs and through goods and services. In that connection, we need to consider how people use technologies both as consumers and as providers of labour in the economy.[7]

The forces surrounding new technologies are not confined to national boundaries. The connections often extend internationally, with firms as parts of global industries. New firms are part of new industries, and enter into variety of competitive and complementary roles in various countries. Globalization of both manufacturing and services in the late 20th century created influential networks of such relationships in the form of global value chains (GVCs). Firms in one industry develop connections with supplier industries and with both businesses and consumers in other countries. These networks also include universities, research centres, and civil society organizations which are part of a country's NIS. They promote international technology transfer, learning and cooperation. Each country's economy then consists of its unique array of firms, some with only local markets and others drawing from and selling into the "traded" or global economy. For firms, each country in which it operates provides a different human resources environment, as well as a different financial, competition, and policy and regulatory environment. At the same time international institutions work to establish shared standards on some of these variables, aiming to level the playing field and help the global economy grow.

Through trade, GVC and changes in production patterns, technological change could critically affect jobs in developing countries (Figure 02). Inequality between countries stems from the particular array of industries a country can grow or attract, which in turn depends on its investments in people and infrastructure as well as its business and regulatory environments. If a country houses only firms in

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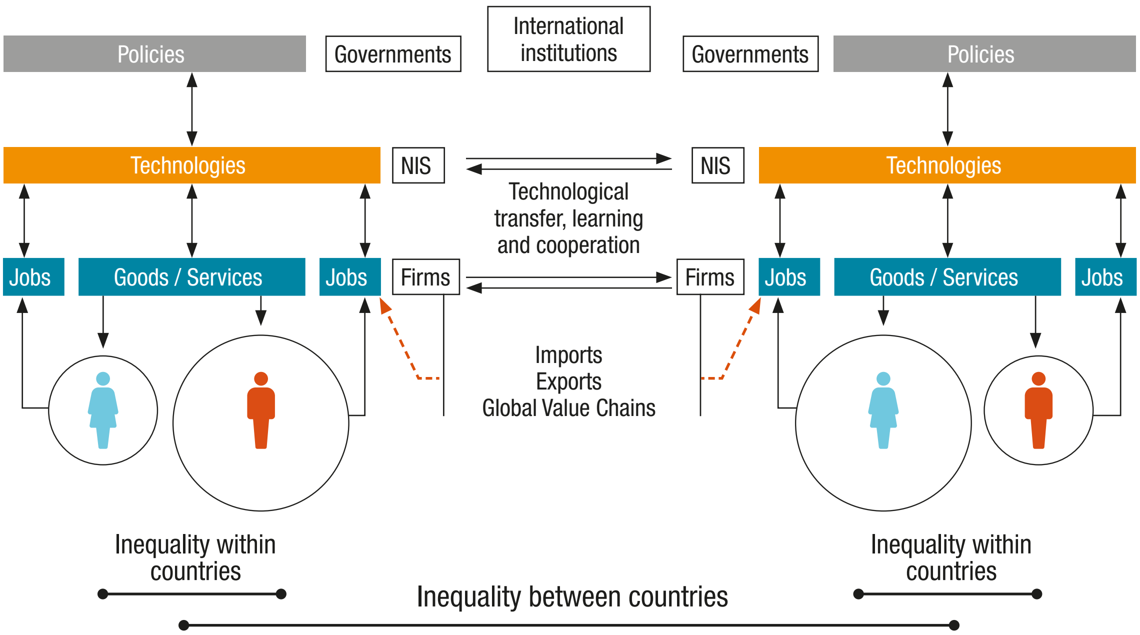
industries that are being displaced through new technologies in the global economy, its people will suffer. If a country is able to establish a role in an industry emerging through rapid technological change, its people may improve their living standards. Multinational firms, however, make their own decisions about where they operate. They may establish facilities and abandon them at will. Smaller countries, and those dependent on firms in a particular industry, are always vulnerable to these external decision processes unless they can encourage local firms to innovate and stay.

Figure 02
Through trade and changes in production patterns, technological change affects jobs in developing countries



Source: UNCTAD.

The adoption of frontier technologies could reduce the labour-cost competitiveness of less industrialized economies. This process may also delay or slow the shift of more traditional industries such as garments, footwear, and low-tech electronics from countries such as China to less-industrialized countries in Asia and Africa. Moreover, while frontier technologies could offer a window of opportunity for developing countries to accelerate economic growth, technological change could also increase the technological gaps between countries and make it even more difficult for less industrialized countries to catch up, reducing the prospects for diversifying their economies and job creation. Given that most people are suppliers of labour, if they are pushed or kept out of labour markets, they will not be able to consume the benefits of most of these technologies.

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1 Sen, 2000
2 Robeyns, 2005
3 Sen, 2000
4 Arthur, 2010
5 Metcalfe et al., 2006
6 UNCTAD, 2012b
7 Inequality also reflects other processes not only production and consumption, but this simplification helps to give focus to the discussion of the relationship between frontier technologies and inequalities in this Report.

ANNEX B. FRONTIER TECHNOLOGY TRENDS

This annex details the status of key frontier technologies, to help analyse the impact of these technologies on sustainable development. Frontier technologies present economic and social opportunities as well as challenges, thus the key features and status of these technologies need to be well understood. This annex covers relevant technical and commercial aspects such as R&D, prices and market structure. The developments in frontier technologies have been so rapid that this attempt can only serve as a snapshot, but it could still offer a good starting point to discuss the potential effects of these technologies on society. Among various frontier technologies, 11 are covered in this annex: AI, IoT, big data, blockchain, 5G, 3D printing, robotics, drones, gene editing, nanotechnology and solar PV.

While discussed independently in the following sections, frontier technologies are increasingly interrelated, and they often expand each other's functionalities. For instance, AI uses big data securely stored in blockchains to improve predictions using machine learning.[8] An increasing number of devices connected within an IoT network are data collection tools that contribute to building up big data.[9] 3D printing can create more complex items that require more data by leveraging big data, and items can be printed remotely through IoT[10] with AI-enabled defect detection functions.[11] Industrial robots assist 3D printing at various production stages such as replacing a printer's build plate, and washing, curing, and final finishing of additively manufactured parts.[12] 5G has the potential to allow near-instantaneous response for robots by dramatically shortening response times.[13]

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A. SUMMARY OF FRONTIER TECHNOLOGIES

1. Artificial Intelligence (AI)

The United States and China have driven research on AI. During the period 1996-2018, there were 403,596 publications related to AI, led by the United States (73,773), China (52,837) and the United Kingdom (22,912). The top three affiliations were Chinese Academy of Sciences (3,414/China), Carnegie Mellon University (2,619/United States) and CNRS Centre National de la Recherche Scientifique (2,510/France). During the same period (1996-2018), there were 116,600 patents filed with the three top assignees' nationalities being the United States (28,963), China (23,298) and Germany (12,056). Top three current owners were BASF (1,961/Germany), Bayer (1,416/Germany) and Siemens (1,320/Germany).

Companies in the United States are the main AI service providers. The top service providers commonly referred to include Alphabet, including their affiliates such as Google and DeepMind, Amazon, Apple, IBM and Microsoft.[14] The top service users, measured by spending on AI, are the retail, banking and discrete manufacturing sectors.[15] Prices of AI depend on the applications and their requirements, but overall AI is becoming affordable.[16] For instance, insurance fraud detection tools cost between $100,000-$300,000 and chatbots are available at a range of $30,000-$250,000.[17]

The AI market ($16 billion in 2017) is growing rapidly.[18] Growth on the supply side of the market is mainly driven by factors such as the expansion of big data, improved productivity, distributed application areas,[19] the availability of large-scale government funding, and advances in image and voice recognition technologies.[20] The major restraint on the supply side is the limited number of AI technology experts.[21] On the demand side, growth is mainly driven by the increasing adoption of cloud-based applications and services, increasing demand for intelligent virtual assistants,[22] and increased client satisfaction.[23] One potential restraint on the demand side is the perceived threat to human dignity by AI although the impact is anticipated to be minimal.[24]

Employment is booming in the AI Industry. AI-related job posts on a worldwide employment-related search engine increased by nearly 100 per cent between June 2015 and June 2018.[25] A study covering 15 countries conducted in 2019 found that China was home to the most AI professionals, with 12,113 AI jobs, followed by the United States (7,465) and Japan (3,369). Software engineer and data scientist are the two most in-demand AI job categories.[26]

Publications
403,596

Patents
116,600

Price
Insurance fraud-detection tool: $100,000–$300,000,
Chatbots:
$30,000–$250,000

Market size
$16 billion (2017)
$191 billion (2024)

Major providers
Alphabet, Amazon, Apple, IBM, Microsoft

Major users
Retail, banking, discrete manufacturing

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2. Internet of Things (IoT)

China and the United States lead research on IoT. During the period 1996-2018, there were 66,467 publications related to IoT, with the most from China (10,081), the United States (7,520) and India (5,700). The three leading affiliations were Beijing University of Posts and Telecommunications (589/China), the Chinese Academy of Sciences (560/China) and the Ministry of Education China (393/China). During the same period, there were 22,180 patents filed, the leading countries of assignees being China (9,515), the Republic of Korea (5,106) and the United States (4,275). The three leading current owners were Samsung Group (2,508/Republic of Korea), Qualcomm (1,213/United States) and Intel (667/United States).

Companies from the United States are major IoT service providers. The IoT providers (IoT platformers) most commonly referred include Alphabet, Amazon, Cisco, IBM, Microsoft, Oracle, PTC, Salesforce and SAP (Germany).[27] In 2018, the leading user sectors, measured by spending on IoT, were consumer, insurance, and healthcare provider.[28] The price of an IoT system depends on the type of application. For instance, ECG monitors range between $3,000 and $4,000, environmental monitoring systems are priced from $10,000, energy management systems cost from $27,000, and building and home automation systems start from $50,000.[29]

The IoT market is already large ($130 billion in 2018) and expanding at a fast pace.[30] The growth on the supply side is driven by factors such as technological advances in semiconductors, offering possibilities for lightweight and efficient devices.[31] On the demand side, the growth is mainly driven by factors such as the rising demand for advanced consumer electronics in growing economies, the increasing adoption of smart devices and internet-enabled devices, the rise of tele-healthcare services and the emergence of automation technology in various sectors.[32] However, cybersecurity risks and privacy concerns could negatively affect market growth.[33]

The growth of the IoT market has led to skill shortages. Research in 2017 showed that the global IoT industry had grown to 2,888 companies employing around 342,000 people, and had a hard time hiring people with the right skills at a speed that could keep pace with the rapid market growth.[34] As of 2017, the companies with the largest number of IoT-related employees were IBM (4,420), Intel Corporation (3,044), Microsoft (2,806), Cisco (2,703) and Ericsson (1,665).[35]

Publications
66,467

Patents
22,180

Price
Electrocardiography monitors: $3,000–$4,000
Building and home automation: from $50,000

Market size
$130 billion (2018)
$1.5 trillion (2025)

Major providers
Alphabet, Amazon, Cisco, IBM, Microsoft, Oracle, PTC, Salesforce, SAP (IoT platform)

Major users
Consumer, insurance, health-care providers

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3. Big data

China and the United States are the frontrunners in big data R&D. During the period 1996-2018, there were 73,957 publications related to big data, the three top source countries being China (15,931), the United States (14,365) and India (4,094). The three leading affiliations were the Chinese Academy of Sciences (1,240/China), Tsinghua University (668/China) and Ministry of Education China (545/China). Within the same period, there were 6,850 patents filed with the top nationality of assignees being China (3,200), the Republic of Korea (1,700) and the United States (1,100). The top three current owners were State Grid Corporation of China (424/China), Huawei (158/China) and IBM (145/United States).

United States companies lead the big data market. The main providers of big data (storage platform, analytics) services include Alphabet, Amazon, Dell Technologies, HP Enterprise, IBM, Microsoft, Oracle, SAP (Germany), Splunk and Teradata.[36] The top user sectors of big data, measured by spending on big data services, are banking, discrete manufacturing and professional services.[37] Prices of big data systems depend on the objective. For example, building and maintaining data warehouses can cost between $19,000 and $25,000 per terabyte (TB) annually, meaning a data warehouse containing 40TB of information (a modest repository for many large enterprises) requires an annual budget of around $880,000, assuming each TB comes with $22,000 in upkeep.[38]

The big data market ($31.93 billion in 2017) is set to expand rapidly.[39] On the supply side, the growth is mainly driven by increasing use of the Internet, and adoption of cloud services and solutions, and increases in the amount of data[40] and the number of mobile devices and apps.[41] However, the lack of skilled workers is inhibiting growth of the big data market.[42] On the demand side, growth is mainly driven by the increasing adoption of big data by the finance sector for risk management and customer service, and greater demand for real-time analytics from various sectors.[43] However, lack of awareness of the benefits of big data, as well as privacy and security concerns, could hinder market growth.[44]

The big data industry is facing a significant shortage of scientists. As more industries adopted big data, the demand for data scientists rose.[45] For instance, in the United States as of 2018, there was a shortage of 151,717 people with data science backgrounds especially in New York City (34,032), the San Francisco Bay Area (31,798) and Los Angeles (12,251).

Publications
73,957

Patents
6,850

Price
Building and maintaining a 40-terabyte data warehouse: $880,000 per year

Market size
$32 billion (2017)
$157 billion (2026)

Major providers
Alphabet, Amazon, Dell, HP, IBM, Microsoft, Oracle, SAP, Splunk, Teradata (storage platforms, analytics)

Major users
Banking, discrete manufacturing, professional services

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4. Blockchain

The United States leads blockchain research. During the period 1996-2018, there were 4,821 publications related to blockchain led by China (760), the United States (749) and the United Kingdom (255). The top three affiliations were Chinese Academy of Sciences (61/China), Beijing University of Posts and Telecommunications (43/China) and Beihang University (31/China). During the same period, there were 2,975 patents filed with the top three assignees' nationalities being the United States (1,277), Antigua and Barbuda (300) and China (270). The top current owners were nChain (336/United Kingdom), Mastercard (181/United States) and IBM (134/United States).

United States companies are the leading blockchain service providers. Top providers of blockchain (blockchain-as-a-service providers)[46] include Alibaba (China), Amazon, IBM, Microsoft, Oracle and SAP (Germany).[47] Top user sectors measured by spending on blockchain services were the finance, manufacturing and retail sectors (IDC, 2019b). Blockchain is a feature-dependent technology, so the final price depends on the specific project requirements. The development cost of a blockchain project typically ranges between $5,000 and $200,000.[48]

The blockchain market is relatively small compared with the other frontier technologies ($708 million in 2017), but it is expected to grow rapidly. On the supply side, the application fields of blockchain have expanded to include financial transactions (online payments and credit and debit card payments) as well as IoT, health and supply chains.[49] Potential market constraints are issues associated with scalability and security, uncertain regulatory standards and difficulties posed by the technology in integration with existing applications.[50] On the demand side, growth is mainly driven increasing by online transactions, digitization of currencies, secure online payment gateways, the growing interest of the banking, financial services and insurance sectors and the number of merchants accepting cryptocurrencies.[51]

The blockchain job market is growing very fast. Demand for blockchain engineers in the United States increased 400 per cent between 2017 and 2018.[52] The average income of a blockchain engineer is around $150,000-175,000 per year, making it higher than the $135,000 average software engineer salary.[53] This trend is further driven by the large technology companies such as Facebook, Amazon, IBM and Microsoft, which are eagerly recruiting talents in this field.[54]

Publications
4,821

Patents
2,975

Price
Development of a project:
$5,000–$200,000

Market size
$708 million (2017)
$61 billion (2024)

Major providers
Alibaba, Amazon, IBM, Microsoft, Oracle, SAP (blockchain-as-a-service)

Major users
Finance, manufacturing, retail

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5. 5G

China and the United States are leading 5G research. During the period 1996-2018, there were 6,828 publications related to 5G with the most from China (981), the United States (618) and the United Kingdom (469). The top affiliations were Beijing University of Posts and Telecommunications (203/China), Nokia Bell Labs (98/United States) and University of Electronic Science and Technology of China (78/China). During the same period, there were 4,161 patents filed with the top nationalities of assignees being the Republic of Korea (3,201), China (396) and the United States (317). The top current owners were Samsung Group (3,388/Republic of Korea), Intel (117/United States) and Huawei (108/China).

Companies from various countries are expected to be the key providers of two important 5G components, network equipment and chips. Companies commonly referred to as 5G network equipment suppliers include Ericsson (Sweden), Huawei (China), Nokia (Finland) and ZTE (China) while in the chipmaker space, the major players commonly referred to are Huawei (China), Intel (United States), MediaTek (Taiwan Province of China), Qualcomm (United States) and Samsung Electronics (Republic of Korea).[55] The three largest 5G-enabled industries by 2026 are likely to be energy utilities, manufacturing and public safety.[56] At the inception stage around 2017 and 2018, prices for 5G technology were available from only a limited number of carriers. In the United States, for example, compared to 4G networks, Verizon charged $10 more per month, AT&T charged $20 more per month (for the mobile hotspot) while T-Mobile kept the price the same.[57] Countries expected to be the early adopters of 5G technologies are the Republic of Korea, China, Japan and the United States.[58]

The 5G market ($608 million in 2018) is expected to more than double every year until 2025.[59] On the supply side, the rollout of 5G takes around five years to achieve broad coverage. One constraint is the need to upgrade the infrastructure such as microcell towers and base stations[60] the costs of which could impede diffusion.[61]

On the demand side, growth is mainly driven by rising demand for mobile broadband, the growing use of smartphones and smart wearable devices, and the increase in mobile video adoption,[62] as well as rapid developments in IoT and the rising number of connected devices, initiatives towards smart cities, and the shift in consumer preference from premise- to cloud-based solutions.[63]

5G is set to create many job opportunities. It is estimated that by 2035, the global 5G value chain, including network operators, core technologies and components providers, OEM device manufacturers, infrastructure equipment manufacturers and content and application developers, will support 22 million jobs globally. China will have the largest number of 5G-related jobs (9.5 million) followed by the United States (3.4 million) and Japan (2.1 million)[64]

Publications
6,828

Patents
4,161

Price
$0–20/month more than 4G network

Market size
$608 million (2018)
$277 billion (2025)

Major providers
Ericsson, Huawei, Nokia, ZTE (network equipment)
Huawei, Intel, MediaTek, Qualcomm, Samsung Electronics (chip)

Major users
Energy utilities, manufacturing, public safety

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6. 3D printing

The United States and China are driving 3D printing research. During the period 1996-2018, there were 17,039 publications related to 3D printing with the most from the United States (4,202), China (2,355) and the United Kingdom (1,103). The top affiliations were Nanyang Technological University (280/Singapore), Chinese Academy of Sciences (182/China) and Ministry of Education China (163/China). Within the same period, there were 13,215 patents filed with the top assignee nationalities being the United States (3,506), China (3,474) and Germany (1,454). The top current owners were Hewlett-Packard (502/United States), Kinpo Electronics (214/Taiwan Province of China) and XYZprinting (213/Taiwan Province of China).

American 3D printer manufacturers lead the industry. Companies commonly referred to as top 3D printer manufacturers include 3D Systems, ExOne Company, HP and Stratasys.[65] The top user sectors measured by spending on 3D printing technology were discrete manufacturing, healthcare and education.[66] In terms of price, over the past years, 3D printers have become more affordable, and the prices are expected to continue to drop in future.[67] Currently, an entry-level 3D printer can cost as little as $200, while a top-notch industrial printer could cost more than $100,000. The average 3D printer for consumers is priced at around $700.[68]

3D printing has been a niche market, but it is now growing at a fast pace. The size of the market measured by revenue was $9.9 billion in 2018[69] and is estimated to reach $44.39 billion by 2025 with a compound annual growth rate of 24 per cent.[70] On the supply side, the growth is mainly driven a wider variety of 3D printable material (major shift from plastic to metal), an increase in the production speed, an increase in the size of printable objects,[71] a reduction in errors and in development cost and time, and the ability to build customized products.[72] Also important is government spending on 3D printing projects.[73] However, the high cost of 3D printing and a scarcity of skilled labour may hamper market growth.[74] On the demand side, growth is mainly driven by an increase in applications in healthcare, consumer electronics, automotive, dentistry, food, fashion and jewellery.[75]

The 3D printing market is rapidly growing, demanding more skilled professionals – for jobs such as engineers, software developers, material scientists and a wide range of business support functions including sales, marketing and other specialists.[76]

Publications
17,039

Patents
13,215

Price
Entry level 3D printer: $200, top-notch industrial printer: $100,000, average 3D printer: $700

Market size
$10 billion (2018)
$44 billion (2025)

Major providers
3D Systems, ExOne, HP, Stratasys

Major users
Discrete manufacturing, healthcare, education

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7. Robotics

Much of the robotics research is in the United States. During the period 1996-2018, there were 254,409 publications related to robotics led by the United States (57,010), China (24,004) and Japan (18,443). The top affiliations were the Chinese Academy of Sciences (2,294/China), Carnegie Mellon University (2,271/United States) and Massachusetts Institute of Technology (1,983/United States). During the same period, there were 59,535 patents filed with the top nationalities of assignees being the United States (31,642), the Republic of Korea (3,751) and Germany (3,228). The top three current owners were Intuitive Surgical (2,615/United States), Johnson & Johnson (1,063/United States) and Boeing (890/United States).

Companies commonly referred to as top manufacturers of industrial robots are ABB (Switzerland), FANUC (Japan), KUKA (China), Mitsubishi Electric (Japan) and Yaskawa (Japan).[77] For humanoids, they are Hanson Robotics (Hong Kong, China), Pal Robotics (Spain), Robotis (Republic of Korea) and Softbank Robotics (Japan).[78] for autonomous vehicles they are Alphabet/Waymo (United States), Aptiv (Ireland), GM (United States) and Tesla (United States).[79] The top user sectors measured by spending on robotics were discrete manufacturing, process manufacturing and resource industries.[80] The price depends on the type of robot. For instance, industrial robots cost $25,000-$400,00,[81] while humanoids are priced between $500 and $2,500,000.[82]

Estimated job growth in robotics is modest. For example, the United States had 132,500 robotics engineers in 2016 and the robotics engineer job market is expected to grow by 6.4 per cent between 2016 and 2026.[83] Robotics careers include robotics engineer, software developer, technician, sales engineer, and operator.[84]

Publications
254,409

Patents
59,535

Price
Industrial robots:
$25,000-$400,000,
humanoids:
$500–$2,500,000

Market size
$32 billion (2018)
$499 billion (2025)

Major providers
ABB, FANUC, KUKA, Mitsubishi Electric, Yaskawa (industrial robots) Hanson Robotics, Pal Robotics, Robotis, Softbank Robotics (humanoids) Alphabet/Waymo, Aptiv, GM, Tesla (autonomous vehicles)

Major users
Discrete manufacturing, process manufacturing, resource industry

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8. Drone

The United States is driving drone research. During the period 1996-2018, there were 10,979 publications related to drones with the most from the United States (2,440), China (1,279) and the United Kingdom (631). The top affiliations were the Chinese Academy of Sciences (128/China), Xidian University (103/China) and National University of Defense Technology (102/China). During the same period, there were 10,897 patents filed with the top nationality of assignees being the United States (2,995), the Republic of Korea (2,068) and France (1,481). The top three current owners were Parrot (325/France), Qualcomm (280/United States) and SZ DJI Technology (242/China).

American companies are major military drone manufacturers while the commercial drone space is filled with companies from other countries. Companies commonly referred to as top manufacturers of commercial drones are 3D Robotics (United States), DJI Innovations (China), Parrot (France) and Yuneec (China), and for military drones they are Boeing (United States), Lockheed Martin (United States) and Northrop Grumman Corporation (United States).[85] Top user sectors measured by spending on drones were utilities, construction, and discrete manufacturing.[86] The price of commercial drones ranges from $50 to $300,000,[87] while $1,000-$4,000 drones are normally considered to be high-end.[88] One commonly used military drone, the General Atomics MQ-9 Reaper, developed primarily for the United States Air Force, costs around $14.5 million per airframe.[89]

Growth in the drone market is expected to be modest. Market revenue was $69 billion in 2017 and is expected to reach $141 billion in 2023, with a CAGR of 13 per cent.[90] On the supply side, digitization and technological improvements in cameras, drone specifications, mapping software, multidimensional mapping, and sensory applications are driving the growth. However, privacy issues and national security regulations are expected to negatively affect the market. One possible competitor is satellite imagery which could impede market growth (unlike aerial imagery by drones, satellite services do not have any regulatory issues.[91] On the demand side, growth is driven by increasing demand for GIS, LiDAR, and mapping services from sectors such as agriculture, energy, tourism, and others.[92] In the military drone market, United States Department of Defense spending is expected to grow only moderately, due to budget constraints and a shift of focus to smaller and less expensive drones.[93]

The drone job market is heating up. In the United States, more than 100,000 drone-related jobs are expected to be added between 2013 and 2025.[94] The top three drone job locations are the United States, China and France. Most sought after are software engineers, followed by hardware engineers and sales.[95]

Publications
10,979

Patents
10,897

Price
Commercial drones: $50–$300,000 (high-end: $1000–$4000), Military drones: $14.5 million (MQ-9 Reaper)

Market size
$69 billion(2017)
$141 billion (2023)

Major providers
3D Robotics, DJI Innovations, Parrot, Yuneec (commercial drones) Boeing, Lockheed Martin, Northrop Grumman Corporation (military drones)

Major users
Utilities, construction, discrete manufacturing

9. Gene editing

Gene editing research is spearheaded by the United States and China. During the period 1996-2018, there were 12,947 publications related to gene editing led by the United States (4,354), China (1,688) and the United Kingdom (822). The top affiliations were the Chinese Academy of Sciences (381/China), Harvard Medical School (353/United States) and the Howard Hughes Medical Institute (234/United States). Within the same period, there were 2,899 patents filed, with the top nationalities of assignees being the United States (1,908), Switzerland (214) and China (212). The top three current owners were Sangamo Therapeutics (179/United States), Broad Institute (140/United States) and Harvard College (135/United States).

United States companies play a major role in providing gene editing services. Companies commonly referred to as top gene editing service providers include CRISPR Therapeutics (Switzerland), Editas Medicine (United States), Horizon Discovery Group (United Kingdom), Intellia Therapeutics (United States), Precision BioSciences (United States) and Sangamo Therapeutics (United States).[96] The users of gene editing include pharma-biotech companies, academic institutes and research centres, agrigenomic companies and contract research organizations.[97] The price of gene editing varies by technology and application. For instance, the cost on average for standard in vitro fertilization procedures using gene editing is over $20,000 for each try, and testing can add $10,000 or more.[98]

The gene editing market is growing, but may be limited by ethical and health concerns. Total market revenue was $3.7 billion in 2018 and is expected to reach $9.7 billion in 2025.[99] On the supply side, the market is driven by increased funding for research and development, and improvement in genetic engineering technologies.[100] On the demand side, the market is driven by increasing cases of genetic and infectious diseases, the use by the food industry of genetically modified crops, and increasing demand for synthetic genes. However, the market could be constrained by ethical issues concerning the misuse of gene editing as well as its potential effects on human health.[101]

Labour demand in gene editing is expected to soar. In the United Kingdom, it is estimated that 18,000 new jobs are to be added between 2017 and 2035,[102] while in the United States, medical scientists and biomedical engineers together are expected to add 17,600 jobs between 2016 and 2026.[103]

Publications
12,947

Patents
2,899

Price
Standard in vitro fertilization: over $20,000/try + $10,000 or more for tests

Market size
$3.7 billion (2018)
$9.7 billion (2025)

Major providers
CRISPR Therapeutics, Editas Medicine, Horizon Discovery Group, Intellia Therapeutics, Precision BioSciences, Sangamo Therapeutics

Major users
Pharma-biotech, academic/ research centre, agrigenomic/contract research organizations

10. Nanotechnology

Nanotechnology research is spearheaded by the United States and China. During the period 1996-2018, there were 152,359 publications related to nanotechnology, with the most from the United States (46,076), China (22,691) and Germany (9,894). The top affiliations were the Chinese Academy of Sciences (4,060/China), Ministry of Education China (2,355/China) and CNRS Centre National de la Recherche Scientifique (1,970/France). Within the same period, there were 4,293 patents filed, with the top nationalities of assignees being the United States (1,075), China (731) and the Russian Federation (696). The top three current owners were Aleksandr Aleksandrovich Krolevets (117/Russian Federation/Individual), PPG Industries (76/United States) and Harvard College (66/United States).

American companies play a major role. Companies commonly referred to as top nanotechnology companies include BASF (Germany), Apeel Sciences (United States), Agilent (United States), Samsung Electronics (Republic of Korea) and Intel Corporation (United States).[104] The most common user sectors of nanotechnology include medicine, manufacturing and energy.[105] The price of nanotechnology technology varies by application. For instance, in 2015, treating ovarian cancer patients with a normal anti-cancer drug, doxorubicin, cost $30/cycle whereas treating with a nanoparticle containing the doxorubicin, Doxil, cost $4,363/cycle.[106]

The nanotechnology market is set to grow at a modest rate. Market revenue was $1.06 billion in 2018 and is expected to reach $2.23 billion by 2025.[107] On the supply side, the market is driven by advances in technology, increasing government support, private sector funding for R&D, and strategic alliances between countries. [108] On the demand side, the market is driven by growing requirements for miniaturization of a wide range of devices.[109] However, there are concerns related to environmental, health, and safety risks, as well as nanotechnology commercialization, that might constrain market growth.[110]

Job market growth is also expected to be modest. In the United States, the nanotechnology engineer market is set to grow by 6.4 per cent between 2016 and 2026.[111] Expected salaries range between $35,000 and $50,000 for associate degrees to $75,000-$100,000 for doctorate degrees.[112]

Publications
152,359

Patents
4,293

Price
Anti-cancer drug with nanotechnology: $4,363/cycle

Market size
$1 billion (2018)
$2.2 billion (2025)

Major providers
BASF, Apeel Sciences, Agilent, Samsung Electronics, Intel

Major users
Medicine, manufacturing, energy

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11. Solar photovoltaic

Solar PV research is led by the United States and China. During the period 1996-2018, there were 10,768 publications related to solar PV with the most from India (2,943), the United States (1,906) and China (957). The top affiliations were Indian Institute of Technology Delhi (422/India), National Renewable Energy Laboratory (127/United States) and Indian Institute of Technology, Bombay (123/India). Within the same period, there were 20,074 patents filed, with the top nationalities of assignees being China (14,515), the Republic of Korea (1,923) and the United States (1,232). the top three current owners were Wuxi Tianyun New Energy Technology (171/China), LG (152/Republic of Korea) and State Grid Corporation of China (152/China).

Chinese companies lead the solar PV market. Companies commonly referred to as top solar panel manufacturers include Jinko Solar (China), JA Solar (China), Trina Solar (China), Canadian Solar (Canada) and Hanwha Q cells (Republic of Korea)[113] The most common user sectors include residential, commercial and utilities.[114] The prices of solar PV panels have decreased significantly, the average upfront cost for the commonly used residential PV system (6kW) dropped from $50,000 to $16,200- $21,420 in ten years. [115]

The solar PV job market growing but uncertainties remain, and there is little evidence of a hiring boom. The recent political and industry turbulence on solar energy will probably continue to constrain employment growth. [116]

Publications
10,768

Patents
20,074

Price
Residential PV system (6kW): $16,200–$21,420

Market size
$54 billion (2018)
$334 billion (2026)

Major providers
Jinko Solar, JA Solar, Trina Solar, Canadian Solar, Hanwha Q cells

Major users
Residential, Commercial, Utilities

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B. TECHNICAL NOTE

1. Publications

Publication data were retrieved from Elsevier's Scopus database of academic publications for the period 1996-2018. This period was chosen because, according to Elsevier, the data on papers published after 1995 are more reliable.[117] The Scopus system is updated retroactively and, as a result, the number of publications for a given query may increase over time.[118] The publication search was conducted using keywords against the title, abstract and author keywords (title-abs-key). The search queries used for each frontier technology are listed below:

Technology	Search query
AI	TITLE-ABS-KEY (ai OR "artificial intelligence") AND PUBYEAR > 1995 AND PUBYEAR < 2019
IoT	TITLE-ABS-KEY (iot OR "internet of things") AND PUBYEAR > 1995 AND PUBYEAR < 2019
Big data	TITLE-ABS-KEY ("big data") AND PUBYEAR > 1995 AND PUBYEAR < 2019
Blockchain	TITLE-ABS-KEY (blockchain) AND PUBYEAR > 1995 AND PUBYEAR < 2019
Robotics	TITLE-ABS-KEY (robotics) AND PUBYEAR > 1995 AND PUBYEAR < 2019
Drone	TITLE-ABS-KEY (drone) AND PUBYEAR > 1995 AND PUBYEAR < 2019
3D printing	TITLE-ABS-KEY ("3D printing") AND PUBYEAR > 1995 AND PUBYEAR < 2019
5G	TITLE-ABS-KEY ("5g communication" OR "5g system" OR "5g network") AND PUBYEAR > 1995 AND PUBYEAR < 2019
Gene editing	TITLE-ABS-KEY (gene-editing OR genome-editing OR "gene editing" OR "genome editing") AND PUBYEAR > 1995 AND PUBYEAR < 2019
Nanotechnology	TITLE-ABS-KEY (nanotechnology) AND PUBYEAR > 1995 AND PUBYEAR < 2019
Solar PV	TITLE-ABS-KEY ("solar photovoltaic" OR "solar pv") AND PUBYEAR > 1995 AND PUBYEAR < 2019

Source: UNCTAD.

2. Patents

Patent publication data were retrieved from the PatSeer database. To align with the publication data, the search period was set as 1996-2018. The patent publication search was conducted using keywords against the title, abstract and claims (TAC). The search queries used for each frontier technology are listed below:

Technology	Search query
AI	TAC:(ai OR "artificial intelligence") AND PBY:[1996 TO 2018]
IoT	TAC:(iot OR "internet of things") AND PBY:[1996 TO 2018]
Big data	TAC:("big data") AND PBY:[1996 TO 2018]
Blockchain	TAC:(blockchain) AND PBY:[1996 TO 2018]
Robotics	TAC:(robotics) AND PBY:[1996 TO 2018]
Drone	TAC:(drone) AND PBY:[1996 TO 2018]
3D printing	TAC:("3D printing") AND PBY:[1996 TO 2018]
5G	TAC:("5g communication" OR "5g system" OR "5g network") AND PBY:[1996 TO 2018]
Gene editing	TAC:(gene-editing OR genome-editing OR "gene editing" OR "genome editing") AND PBY:[1996 TO 2018]
Nanotechnology	TAC:(nanotechnology) AND PBY:[1996 TO 2018]
Solar PV	TAC:("solar photovoltaic" OR "solar pv") AND PBY:[1996 TO 2018]

Source: UNCTAD.

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3. Market size

Market size data, as measured by the revenue generated in the market, is based on various market research reports available online. Since each market research report yields somewhat different numbers, the market size data was collected so that the compound annual growth rate (CAGR) was the largest. Also, the number of years between the base year and the prediction year used to calculate the CAGR varies by technology, ranging from six to nine years.

4. Frontier technology providers

Since there was no structured, reliable information about market share or company profit readily available for frontier technologies, the top frontier technology providers were identified through an online search, listing companies most commonly referred to as top providers. The number of companies listed is not the same across the 11 frontier technologies because there is no effective way to narrow down the list to the same number for each technology. Moreover, the online search was conducted in English, potentially leading to more favourable results for companies from English-speaking countries. Therefore, the technology providers information is indicative only and needs to be interpreted cautiously.

5. Frontier technology users

Frontier technology users (sectors) are ranked according to the scale of spending by the user sectors of each technology. The exceptions were 5G, gene editing, nanotechnology and solar PV for which spending data was not available and hence estimates available online were used instead.

8 Maryville Online, 2017; Skalex, 2018)
9 Yost, 2019)
10 Digital Magazine, 2016
11 Gaget, 2018
12 AMFG, 2018
13 Ramos, 2017
14 Ball, 2017; Patil, 2018; Botha, 2019
15 IDC, 2019c
16 Azati, 2019
17 Halsey, 2017
18 MarketsandMarkets, 2018
19 MarketWatch, 2019i
20 Grand View Research, 2017
21 MarketsandMarkets, 2018
22 MarketsandMarkets, 2018
23 MarketWatch, 2019i
24 MarketWatch, 2019i
25 Overmyer, 2018
26 Rayome, 2019
27 DA-14, 2018; J. Lee, 2018; Rana, 2019
28 Business Wire, 2018
29 Singh, 2018
30 Froese, 2018
31 Research Nester, 2019
32 Research Nester, 2019
33 Verified Market Research, 2019
34 Bjorlin, 2017
35 Buntz, 2017
36 Verma, 2018; MarketWatch, 2019a; SoftwareTestingHelp, 2020
37 IDC, 2019d
38 Aziza, 2019
39 MarketWatch, 2019a
40 MarketWatch, 2019e
41 MarketWatch, 2019a
42 MarketWatch, 2018b
43 MarketWatch, 2019e
44 MarketWatch, 2019a
45 LinkedIn, 2018
46 Blockchain-as-a-Service (BaaS) is when an external service provider sets up all the necessary blockchain technology and infrastructure for a customer for a fee. By paying for BaaS, a client pays the BaaS provider to set up and maintain blockchain connected nodes on their behalf. A BaaS provider handles the complex back-end for the client and their business.
47 Akilo, 2018; Patrizio, 2018; Anwar, 2019
48 Azati, 2019
49 MarketWatch, 2019g
50 Market Research Future, 2019
51 Grand View Research, 2019
52 Rodriguez, 2018
53 Hired, 2020
54 Rodriguez, 2018
55 Auchard and Nellis, 2018; La Monica, 2019; Whatsag, 2020
56 Reichert, 2017
57 Horwitz, 2018; Kinney, 2019
58 SDxCentral, 2017
59 Raza, 2019
60 Maddox, 2018
61 MarketWatch, 2019d
62 Business Wire, 2019
63 MarketWatch, 2019d
64 Campbell et al., 2017
65 Vanakuru, 2018; Neufeld, 2019; Wagner, 2019a
66 IDC, 2019a
67 PwC, 2020)
68 3D Insider, 2017
69 MarketsandMarkets, 2019
70 Sawant and Kakade, 2018
71 Stewart, 2018
72 Sawant and Kakade, 2018
73 MarketsandMarkets, 2019
74 Sawant and Kakade, 2018
75 Grand View Research, 2018; Sawant and Kakade, 2018
76 Bunger, 2018
77 MarketWatch, 2018a; Technavio, 2019
78 MarketWatch, 2018a; The Express Wire, 2019; Mordor Intelligence, 2020b
79 Yuan, 2018; Technavio, 2018b; Mitrev, 2019
80 IDC, 2018
81 Motion Controls Robotics, 2016
82 Smashing Robotics, 2012
83 CareerExplorer, 2020a
84 Grad School Hub, 2020
85 Technavio, 2018a; FPV Drone Reviews, 2019; Joshi, 2019
86 IDC, 2018
87 Noble, 2019
88 Flynt, 2018

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[89] Gettinger, 2015
[90] TechSci Research, 2018
[91] Lanjudkar, 2017
[92] Lanjudkar, 2017
[93] Freedonia, 2020
[94] Jenkins and Vasigh, 2013
[95] Radovic, 2019
[96] Schmidt, 2017; Philippidis, 2018; Acharya, 2019
[97] GlobeNewswire, 2019a
[98] Hercher, 2018
[99] GlobeNewswire, 2019b
[100] GlobeNewswire, 2019a
[101] GlobeNewswire, 2019a; MarketWatch, 2019b, 2019f; Plumer et al., 2018
[102] Thompson, 2017
[103] Bureau of Labor Statistics, U.S. Department of Labor, 2019a, 2019b
[104] Venture Radar, 2020
[105] Cox, 2019; Nano.gov, 2020
[106] Parker, 2016
[107] Tewari and Baul, 2019
[108] MarketWatch, 2019h
[109] MarketWatch, 2019h
[110] MarketWatch, 2019h
[111] CareerExplorer, 2020b
[112] Peterson’s, 2017
[113] Infiniti Research, 2017; Lapping, 2017; Zong, 2019
[114] Doshi, 2017
[115] Sendy, 2018
[116] Chamberlain, 2018
[117] Shoham et al., 2018
[118] Shoham et al., 2018

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ANNEX C. HOW TECHNOLOGIES AFFECT INEQUALITIES IN THE USER'S PERSPECTIVE

Frontier technologies could impact inequality through the products (goods and services) that use or are produced and distributed using these technologies. This Report adopts elements from the Capability Approach[1] to identify the channels through which products that apply frontier technologies affect inequalities. There is a sizeable literature that applies the Capability Approach to technology, particularly in the area of ICT, although there are still many areas of debate.[2]

Products that apply frontier technologies (e.g. AI systems, industrial robots, drones, gene editing therapies, solar PV systems) have characteristics that can give people certain capabilities to function (e.g. improved decision, strength, move objects across long distances, become free from disease, use electricity) (Figure 01). A particular technology can be applied in a multitude of products (goods and services); therefore, in the discussion of the frontier technologies and inequalities, it is essential to have in mind what specific product we are talking about. In the case of many of the frontier technologies, which have characteristics of general-purpose technologies that can be used in many contexts and in the development of several other technologies, this consideration becomes even more important.

A critical element is the characteristics of a product. These characteristics are a combination of the results of the design of these products, which determines their technical characteristics (e.g. unit cost, aesthetics, weight, size, performance), and the business models used for bringing them into reality, which determine the market characteristics of these products (e.g. target user, unit price, delivery channels). These market characteristics exist even when the product is not traded in the market, but is, for example, provided publicly by the government or through another non-market mechanism. Those technical and market characteristics define, in their turn, what the product is, its purpose, where and when it is available.

The products that apply frontier technologies can give people some capabilities (increased choice) depending on personal, social, and environmental factors. The availability of the product combined with the interaction of the product with the factors mentioned above determine the access that a person has to that particular product. Therefore, the design and business model for the provision of a product, combined with the diverse conversion factors of different people, result in differences in access to these products.

Access in this context can be described by: availability, affordability, awareness, accessibility, and the ability for effective use of the technology.[3] The differential access to the goods and services that apply technologies could reinforce inequalities. For example, those that get access to the benefits of the technology first get ahead, and usually, they are those already well-off in the first place. First users can also influence the development of the technology itself via user-producer interactions, helping make the technology evolve in a direction more aligned with their needs and context. The differential access to products is itself the result of previous disparities (e.g. in income levels), in a vicious cycle.

Unequal access is not a particular feature of products that apply frontier technologies. Not all innovations are the result of an explicit effort to make the end product, for example, more affordable. As with any new technology, many companies, when they innovate and develop new goods and services, they tend to focus on higher-income consumers that can bear the higher initial prices of these products. High-income consumers benefit from new technologies first, but they end up paying the costs of further development and diffusion of new technologies. Similarly, in terms of availability and awareness, products cannot reach the whole world at the same time. In terms of ability to use and accessibility, not everyone may be able to use the product.

The social context also affects access to technology. For example, social norms can restrict access to technology for women, ethnic minorities and other disadvantaged groups, even within the same household.

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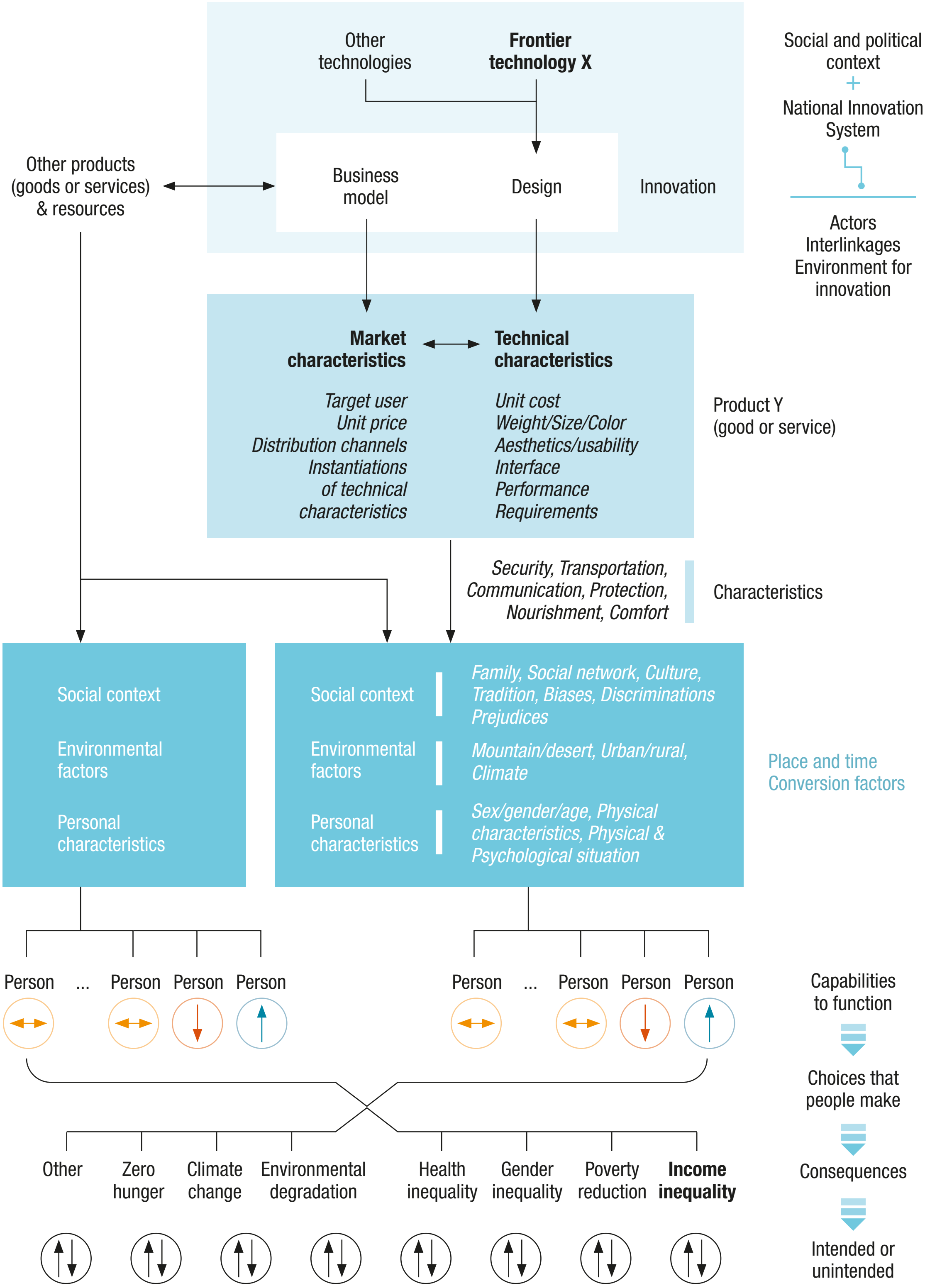
Figure 03
Conceptual framework from frontier technologies to inequalities



Source: UNCTAD.

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However, having the access (in the broader definition used above) to the products that use frontier technologies, and therefore the capabilities associated with them, does not mean that a person realizes those capabilities automatically. It depends on the choices that people make. The aggregation of the choices that people make (including people who do not have access to the products that apply frontier technologies) affect developmental outcomes such as inequality (in its various dimensions), poverty reduction, environmental protection, and climate change. These consequences do not have to necessarily move in the same direction (towards positive outcomes). An innovation applying frontier technology could, for example, contribute to reducing poverty (e.g. use of blockchain to enable a cryptocurrency that can be used to send remittances) and at the same time be harmful to the environment (e.g. high need for energy in some of the cryptocurrency systems).

Products and services can also reduce the capabilities of people, either directly, for example when a person takes a particular medicine, and that causes a severe adverse side effect, or indirectly through some externality of the use by other people, for example through pollution. Therefore, technologies are used in products that could benefit or harm people. In fact, it is possible that technologies are beneficial for some people and harm some other people at the same time. Or even that it benefits some people in some dimension (e.g. economic) and harm some of these same people in some other dimension (e.g. environmental).

These implications of the products that apply the technology could be intended or unintended consequences, based on the design and business model of the provision of the products.

The products that use frontier technologies are the fruit of innovations that emerge from the national system of innovation. Therefore, these innovations reflect the context and biases of the actors of the innovation system. Technology in itself is not neutral as it is developed in specific social and political contexts which shape its attributes.

In summary, the design and business models affect the access (in broader terms) to the products that apply frontier technologies, which could affect inequalities. Those that have access to the technology first get an advantage. Inequalities in access to frontier technologies are the result of existing disparities and reinforce those inequalities. Design and business models could also affect the consequences of the use of the products that apply frontier technologies, intentionally or unintentionally, also affecting inequalities (among other developmental outcomes). Therefore, to contribute to reducing inequalities and to sustainable development, products that use frontier technologies should be designed, and the business models to bring them into the market should be developed, taking into consideration the access to these products and the intended and unintended consequences of their use.

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[1] Sen, 2000

[2] Johnstone, 2007; Kleine, 2011, 2013; Oosterlaken, 2013, 2015

[3] Roberts, 2017; Hernandez and Roberts, 2018

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ANNEX D. AI ETHICS FRAMEWORKS, GUIDELINES, AND STATEMENTS

Organization / Institution	Title	Region	Sector	Year	Type
Academy of Medical Royal Colleges	Artificial Intelligence in Healthcare	United Kingdom	Academia	2019	Advice
Accenture	Universal Principles of Data Ethics	United States	Private sector	2016	Advice
Accenture UK	Responsible AI and robotics. An ethical framework	United Kingdom	Private sector	2018	Advice
ADEL	ADEL	France	Private sector	2018	Binding agreement
Advisory Board on Artificial Intelligence and Human Society	Report on Artificial Intelligence and Human Society (Unofficial translation)	Japan	Government	2017	Advice
Agenzia per l'Italia Digitale (AGID)	L'intelligenzia artificiale al servizio del cittadino (Artificial Intelligence at the service of the citizen)	Italy	Government	2018	Advice
AI Now Institut	AI Now Report 2018	United States	Academia	2018	Advice
American College of Radiology; European Society of Radiology; Radiology Society of North America; Society for Imaging Informatics in Medicine; European Society of Medical Imaging Informatics; Canadian Association of Radiologists; American Association of Physicists in Medicine	Ethics of Artificial Intelligence in Radiology: Summary of the Joint European and North American Multisociety Statement	International	Professional association	2019	Advice
American Medical Association (AMA)	Policy Advices on Augmented Intelligence in Health Care H-480.940	United States	Professional association	2018	Advice
Amnesty International/ Access Now	The Toronto Declaration	United Kingdom	Civil society	2018	Advice
Aptiv, Audi, BMW, Daimler and other automotive companies	Safety First for Automated Driving – Proposed technical standards for the development of Automated Driving	International	Private sector	2019	Voluntary commitment
Association for Computing Machinery	Statement on Algorithmic Transparency and Accountability	United States	Industry association	2017	Binding agreement
Association for Computing Machinery - Future of Computing Machinery	It's Time to Do Something: Mitigating the Negative Impacts of Computing Through a Change to the Peer Review Process	United States	Industry association	2019	Advice
Atomium - EISMD (AI4Poeple)	AI4People's Ethical Framework for a Good AI Society: Opportunities, Risks, Principles, and Advices	European Union	Civil society	2018	Advice
Australian Government/ Department of industry, Innovation and Science	Artificial Intelligence Australia's Ethics Framework A Discussion Paper	Australia	Government	2019	Advice

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Beijing Academy of Artificial Intelligence	Bejing AI Principles	China	Government	2019	Advice
Bertelsmann Stiftung / iRights.Lab	Algo.Rules	Germany	Civil society	2019	Advice
Bitkom	Leitlinien für Big Data Einsatz (Guidelines for the use of Big Data)	Germany	Industry association	2015	Advice
Bitkom	Empfehlungen für den verantwortlichen Einsatz von KI und automatisierten Entscheidungen (Advices for the responsible use of AI and automated decision making)	Germany	Industry association	2018	Advice
Bundesministerium des Innern, für Bau und Heimat/ Datenethikkommission der Bundesregierung	Gutachten der Datenethikkommission der Bundesregierung	Germany	Government	2019	Advice
Bundesverband KI	KIBV Gütesiegel (KIBV Quality seal)	Germany	Industry association	2019	Voluntary commitment
Center for Democracy & technology (CDT)	Digital Decisions	United States	Civil society	n/a	Advice
Chinese AI Alliance	Joint Pledge on Artificial Intelligence Industry Self-Discipline (Draft for Comment)	China	Other	2019	Voluntary commitment
Chinese Government	Governance Principles for a New Generation of Artificial Intelligence: Develop Responsible Artificial Intelligence	China	Government	2019	Advice
CIGI Gentre for International Governance Innovation	CIGI Paper No. 178: Toward a G20 Framework for Artificial Intelligence in the Workplace	Canada	Civil society	2018	Advice
CIGREF	Digital Ethics	France	Industry association	2018	Advice
Commission de Surveillance du Secteur Financier	Artificial Intelligence: opportunities, risks and Advices for the financial sector	Luxembourg	Government	2018	Advice
Council of Europe	Artifical Intelligence and Data Protection	European Union	Government	2018	Advice
Data & Society	Governing Artificial Intelligence. Upholding Human Rights & Dignity	United States	Civil society	2018	Advice
Data Ethics	Data Ethics Principles	Denmark	Civil society	2017	Advice
DataforGood	Serment d'Hippocrate pour Data Scientist (Hippocratic Oath for Data Scientists)	France	Civil society	n/a	Voluntary commitment
Datatilsynet The Norwegian Data Protection Authority	Artificial intelligence and privacy	Norway	Government	2018	Advice
Deep Mind	Saftey and Ethics	United States	Private sector	n/a	Voluntary commitment
Department of Health and Social Care	Code of conduct for data-driven health and care technology	United Kingdom	Government	2019	Advice
Deutsche Telekom	Guidelines for Artificial Intelligence	Germany	Private sector	2018	Voluntary commitment

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DGB	Künstliche Intelligenz und die Arbeit von Morgen	Germany	Civil society	2019	Advice
Digital Catapult, Machine Intelligence Garage Ethics Committee	Ethics Framework -Responsible AI	United Kingdom	Private sector	2020	Advice
Dubai	Artificial Intelligence Ethics and Principles, and toolkit for implementation	United Arab Emirates	Government	2019	Advice
Ekspertgruppen om Design: malenehald.dk DATAETIK (Danish Expert Group on Data Ethics)	Data for the Benefit of the People: Advices from the Danish Expert Group on Data Ethics	Denmark	Government	2018	Advice
Engineering and Physical Research Council	Principles of Robotics	United Kingdom	Government	2010	Advice
Ethikbeirat HR Tech (Ethics council HR Tech)	PDF: Richtlinien für den verantwortungsvollen Einsatz von Künstlicher Intelligenz und weiteren digitalen Technologize in der Personalarbeit (Guidelines for the responsible use of artificial intelligence and other digital technologies in human resources); Consultation document	Germany	Private sector	2019	Voluntary commitment
Ethkikkommission BuMi Verkehr und digitale infrastruktur	Automatisiertes und Vernetztes Fahren / Automated and connected automated driving	Germany	Government	2017	Advice
European Commision For the Efficiency of Justice	European ethical Charter on the use of Artificial Intelligence in judicial systems and their environment	International	Government	2018	Advice
European Commission	Code of Practice on Disinformation	European Union	Government	2018	Advice
European Group on Ethics in Science and New Technologies	Statement on Artificial Intelligence, Robotics and Autonomous Systems	European Union	Government	2018	Advice
European Parliament	Report with Advices to the Commission on Civil Law Rules on Robotics	European Union	Government	2017	Advice
Executive Office of the President; National Science and Technology Council; Committee on Technology	Preparing for the future of Artificial Intelligence	United States	Government	2016	Advice
Faculty of Informatics, TU Wien	Vienna Manifesto on Digital Humanism	Austria	Academia	2019	Voluntary commitment
FAT/ML	Principles for Accountable Algorithms and a Social Impact Statement for Algorithms	International	Civil society	n/a	Advice
Fraunhofer Institute for Intelligent Analysis and Information Systems IAIS	Trustworthy Use of Artificial Intelligence	Germany	Academia	2020	Advice
French Data Protection Authority (CNIL)	How can humans keep the upper hand? Report on the ethical matters raised by AI algorithms	France	Government	2017	Advice

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French National Ethical Consultative Committee for Life Sciences and Health (CCNE	Digital Technology and Healthcare. Which Ethical Issues for which Regulations?	France	Government	2014	Advice
French Strategy for Artifical Intelligence	For a meaningful Artificial Intelligence. Towards a French and European strategy	France	Government	2018	Advice
Future Advocacy	Ethical, social, and political challenges of Artificial Intelligence in Health	United Kingdom	Civil society	2018	Advice
Future of Life Institute	Asilomar AI Principles	United States	Civil society	2017	Voluntary commitment
Future of Privacy Forum	Unfairness by algorithm: Distilling the Harms of automated decision making	United States	Civil society	2017	Advice
G20	Principles for responsible stewardship of trustworthy AI	International	Intergovernmental organisation	2019	Voluntary commitment
Gesellschaft für Informatik (German Society of Informatics)	Ethische Leitlinien (Ethical Guidelines)	Germany	Professional association	2018	Voluntary commitment
Google	People & AI Partnership Guidebook	United States	Private sector	n/a	Advice
Google	Responsible AI Practice	United States	Private sector	n/a	Advice
Google	Advanced Technology External Advisory Council for Google (ATEAC)	United States	Private sector	2019	Binding agreement
Google	Objectives for AI Applications	United States	Private sector	2018	Voluntary commitment
Government of Canada	Directive on Automated Decision-Making	Canada	Government	2019	Binding agreement
Government of Canada	Responsible use of artificial intelligence (AI)	Canada	Government	2019	Voluntary commitment
Government of Canada	Responsible Artificial Intelligence in the Government of Canada (whitepaper)	Canada	Government	2019	Advice
Handelsblatt Research Institute	Datenschutz und Big Data / Data protection and Big Data	Germany	Other	n/a	Advice
High Level Expert Group on AI (European Commission)	Draft Guidelines for Trustworthy AI	European Union	Government	2019	Advice
Hochschule der Medien	10 ethische Leitlinien für die Digitalisierung von Unternehmen (10 ethical guidelines for the digitalisation of companies)	Germany	Academia	2017	Advice
IA Latam	Declaración de Ética para desarrollo y uso de la Inteligencia Artificial/ Declaration of Ethics for the Development and Use of Artificial Intelligence	International	Private sector	2019	Voluntary commitment
IBM	IBM's Principles for Trust and Transparency	United States	Private sector	2018	Voluntary commitment
IBM	Trusted AI	United States	Private sector	n/a	Advice

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IBM	Everyday Ethics for Artificial Intelligence	United States	Private sector	n/a	Advice
Icelandic Institute for Intelligent Machines	IIIM's Ethics Policy	Iceland	Civil society	n/a	Voluntary commitment
IEEE	Ethically Aligned Design 2	International	Professional association	2019	Advice
IEEE	Ethics in Action – Set the Global Standards	International	Professional association	n/a	Advice
IEEE	Ethically Aligned Design	United States	Professional association	2019	Advice
Information Commissioner's Office	Big data, artificial intelligence, machine learning and data protection	United Kingdom	Government	2017	Advice
Information Technolgy Industry Council	AI policies and principles	United States	Industry association	2017	Voluntary commitment
Institute for Business Ethics	Business Ethics and Artificial Intelligence	United Kingdom	Other	2018	Advice
Institute for Information and Communications Policy (IICP), The Conference toward AI Network Society	Draft AI R&D Guidelines for International Discussions	Japan	Government	2017	Advice
Intel Corporation	Intel's AI Privacy Policy White Paper. Protecting individuals' privacy and data in the artificial intelligence world	United States	Private sector	2018	Advice
Intel Corporation	Artificial Intelligence. The Public Policy Opportunity	United States	Private sector	2017	Advice
International Conference of Data Protection and Privacy Commissioners	DECLARATION ON ETHICS AND DATA PROTECTION IN ARTIFICAL INTELLIGENCE	International	Professional association	2018	Voluntary commitment
Internet Society	Artifical Intelligence and Machine Learning Policy Paper	United States	Civil society	2017	Advice
ITechLaw	Responsible AI: Global Policy Framework	United States	Professional association	2019	Advice
Japanese Society for AI	The Japanese Society for Artificial Intelligence Ethical Guidelines	Japan	Academia	2017	Voluntary commitment
Kakao Corp	Kakao Algorithm Ethics	South Korea	Private sector	n/a	Voluntary commitment
Konferenz der unabhängigen Datenschutzaufsichtsbehörden des Bundes und der Länder (Conference of the independent data protection supervisory authorites in Germany)	Hambacher Erklärung zur Künstlichen Intelligenz – Sieben datenschutzrechtliche Anforderungen (Hambach Declaration on Artificial Intelligence – seven requirements for data protection)	Germany	Other	2019	Voluntary commitment
Korean Ministry of Science, ICT and Future Planning (MSIP)	Mid- to Long-Term Master Plan in Preparation for the Intelligent Information Society Managing the Fourth Industrial Revolution	South Korea	Government	2016	Voluntary commitment

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Leaders of the G7	Charlevoix Common Vision for the Future of Artificial Intelligence	International	Government	2018	Voluntary commitment
Machine Intelligence Research Institute	The Ethics of Artifical Intelligence	United States	Academia	n/a	Advice
Massachusetts Institute of Technology	MIT Schwarzman College of Computing Task Force Working Group on Social Implications and Responsibilities of Computing Final Report	United States	Academia	2019	Advice
Microsoft	Responsible bots: 10 guidelines for developers of conversational AI	United States	Private sector	2018	Voluntary commitment
Microsoft	Facial Recognition Principles	United States	Private sector	2018	Voluntary commitment
Microsoft	The Future Computed – Artificial intelligence and its role in society	United States	Private sector	2019	Advice
Microsoft	Our Approach to AI	United States	Private sector	n/a	Voluntary commitment
Mission Villani	For a meaningful Artificial Intelligence. Towards a French and European strategy	France	Government	2018	Advice
Monetary Authority of Singapore	Principles to Promote Fairness, Ethics, Accountability and Transparency (FEAT) in the Use of Artificial Intelligence and Data Analytics in Singapore's Financial Sector	Singapore	Government	2018	Advice
Mozilla Foundation	Effective Ad Archives	United States	Civil society	2019	Advice
National Institution for Transforming India (Niti Aayog)	Discussion Paper: National Strategy for Artificial Intelligence	India	Government	2018	Advice
National Research Council Canada	Advisory Statement on Human Ethics in Artificial Intelligence and Big Data Research (2017)	Canada	Government	2019	Binding agreement
National Science and Technology Council; Networking and Information Technology Research and Development Subcommittee	The National Artificial Intelligence Research and Development Strategic Plan	United States	Government	2019	Advice
New York Times	Seeking Ground Rules for A.I.	United States	Private sector	2019	Advice
No organisation	Holberton Turing Oath	International	Civil society	No Date	Voluntary commitment
OECD	Advice of the Council on Artificial Intelligence	International	International organisation	2019	Advice
OP Financial Group	OP Financial Group's ethical guidelines for artificial intelligence	Finland	Private sector	n/a	Voluntary commitment
Open AI	Open AI Charter	United States	Civil society	2018	Voluntary commitment
Oxford Munich Code of Conduct	Code of Conduct	International	Academia	2019	Voluntary commitment
Partnership On AI (Apple, Amazon, Google, MS, etc)	Tenets Partnership on AI	International	Private sector	n/a	Voluntary commitment

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Personal Data Commission Singapore	A Proposed Model Artificial Intelligence Governance Framework	Singapore	Government	2019	Advice
Pervade at University of Maryland	Pervasive Data Ethics	United States	Academia	n/a	Voluntary commitment
Philips	Five guiding principles for responsible use of AI in healthcare and healthy living	Netherlands	Private sector	2020	Advice
Policy Action Network	AI & Data Topical Guide Series	South Africa	Civil society	2020	Advice
Pontifical Academy for Life	Rome Call – AI Ethics	Italy	Religious institution	2020	Voluntary commitment
PriceWaterhouseCoopers UK	A practical guide to Responsible Artificial Intelligence (AI)	United Kingdom	Private sector	2019	Advice
Privacy International & Article 19	Privacy and Freedom of Expression In the Age of Artificial Intelligence	United Kingdom	Civil society	2018	Advice
Republic of Užupis	Užupis Principles for Trustworthy AI Design	Lithuania	Civil society	2019	Advice
reputable AI	The Principles	International	Private sector	nodate	Binding agreement
Sage	The Ethics of Code: Developing AI for Business with Five Core Principles	United States	Private sector	2017	Voluntary commitment
SAP	SAP's guiding principles for Artificial Intelligence	Germany	Private sector	2018	Voluntary commitment
Science, Law and Society (SLS) Initiative	Principles for the Governance of AI	United States	Civil society	2017	Advice
Software & Information Industry Association (SIIA)	Ethical Principles for Artificial Intelligence and Data Analytics	International	Private sector	2017	Advice
Sony	Sony Group AI Ethics Guidelines	Japan	Private sector	2019	Voluntary commitment
Stats New Zealand and Office of the Privacy Commissioner	Principles for the safe and effective use of data and analytics	New Zealand	Government	2018	Advice
Swiss Alliance for Data-Intensive Services	Ethical Codex for Data-Based Value Creation: For Public Consultation	Switzerland	Industry association	2019	Advice
Telefonica	Principos / Principles	Spain	Private sector	2018	Binding agreement
Telia Company	Telia Company Guiding Principles on trusted AI ethics	Sweden	Private sector	n/a	Voluntary commitment
The Alan Turing Institute	Understanding artificial intelligence ethics and safety	United Kingdom	Academia	2019	Advice
The Critical Engineering Working Group	THE CRITICAL ENGINEERING MANIFESTO	Germany	Civil society	2019	Voluntary commitment
The Good Technology Collective	The Good Technology Standard (GTS:2019-Draft-1)	International	Civil society	2018	Advice
The Greens (Green Working Group Robots)	Position on Robotics and Artificial Intelligence	European Union	Other	2016	Advice

The Humanitarian Data Science and Ethics Group	A Framework for the Ethical use of advanced Data Science Methodes in the Humanitarian Sector	European Union	Academia	2020	Advice
The Information Accountability Foundation	Unified Ethical Frame for Big Data Analysis (draft)	United States	Civil society	2015	Advice
The Institute for Ethical and Machine Learning	The Responsible Machine Learning Principles	United Kingdom	Civil society	n/a	Advice
The Internet Society	Artificial Intelligence and Machine Learning: Policy Paper	United States	Civil society	2017	Advice
The Leadership Conference on Civil and Human Rights	Civil Rights Principles for the Era of Big Data	United States	Civil society	2014	Advice
The Open Data Institute	Data Ethics Canvas	United Kingdom	Civil society	2019	Advice
The Public Voice	Universal Guidelines for Artificial Intelligence	International	Civil society	2018	Advice
The Rathenau Instituut, Special Interest Group on Artificial Intelligence (SIGAI), ICT Platform Netherlands (IPN)	Dutch Artificial Intelligence Manifesto	Netherlands	Government	2017	Advice
The Royal Society	Machine learning: the power and promise of computers that learn by example	United Kingdom	Academia	2017	Advice
The White House	Guidance for Regulation of Artificial Intelligence Applications	United States	Government	2020	Binding agreement
Tieto	Tieto's AI ethics guidelines	Finland	Private sector	2018	Voluntary commitment
UK Government	A guide to using Artificial Intelligence in the public sector	United Kingdom	Government	2019	Advice
UK House of Lords	UK House of Lords Artificial Intelligence Committee's report, AI in the UK: ready, willing and able?	United Kingdom	Government	2018	Advice
Unesco	Unesco Global Code of Ethics	International	Intergovernmental organisation	n/a	Advice
UNESCO	Preliminary study on the Ethics of Artificial Intelligence	France	Civil society	2019	Advice
UNESCO	Report of COMEST on Robotics Ethics	International	International organisation	2010	Advice
UNI Global Union	Top 10 Principles for Ethical Artificial Intelligence	International	Civil society	2017	Advice
United Nations University Institute	A Typological Framework for Data Marginalization	China	Academia	2019	Advice
Unity	Unity's six guiding AI principles	United States	Private sector	2018	Voluntary commitment
Université de Montréal	Montreal Declaration for Responsible AI	Canada	Academia	2018	Voluntary commitment
University of Notre Dame	A Code of Ethics for the Human Robot Interaction	United States	Academia	n/a	Advice
University of Oxford - Future of Humanity Institute	AI Governance: A research agenda	United Kingdom	Academia	2017	Advice

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University of Oxford a.o.	The Malicious Use of Artificial Intelligence: Forecasting, Prevntion and Mitigation	International	Academia	2018	Advice
Utrecht University	Data Ethics Decision Aid (DEDA)	Netherlands	Academia	2017	Advice
UX Studio Team	AI UX: 7 Principles of Designing Good AI Products	Hungary	Private sector	2018	Advice
Ver.di	Künstliche Intelligenz – Gemeinwohl als Maßstabm Gute Arbeit als Prinzip	Germany	Civil society	2019	Advice
Verbraucherzentrale Bundesverband e.V. (Federal Association of Consumer Protection Centres)	Algorithmenbasierte Entscheidungsprozesse (Algorithmic decision-making processes)	Germany	Civil society	2017	Advice
Verivox	Verivox/Pro7 Selbstverpflichtung (Commitment)	Germany	Private sector	2019	Voluntary commitment
Vodafone Group	Vodafone AI Framework	United Kingdom	Private sector	2019	Voluntary commitment
W20	Artificial Intelligence: open questions about gender inclusion	International	Civil society	2018	Advice
Webfoundation	Artificial Intelligence: open questions about gender inclusion	Switzerland	Civil society	2018	Advice
Women leading in AI	Principles for Responsible AI	International	Civil society	2019	Advice
Work in the age of artificial intelligence. Four perspectives on the economy, employment, skills and ethics	Ministry of Economic Affairs and Employment / Finland	Finland	Government	2018	Advice
Working group "Vernetzte Anwendungen und Plattformen für die digitale Gesellschaft"	Charta of digital networking	Germany	Private sector	2014	Voluntary commitment
World Economic Forum	A Framework for Responsible Limits on Facial Recognition Use Case	United States	Civil society	2020	Advice
World Economic Forum	White Paper: How to Prevent Discriminatory Outcomes in Machine Learning	International	Civil society	2018	Advice

Sources: AlgorithmWatch AI Ethics Global Inventory (https://inventory.algorithmwatch.org/); Council of Europe Ethical Frameworks (https://www.coe.int/en/web/artificial-intelligence/ethical-frameworks); NESTA AI Governance Database (https://www.nesta.org.uk/data-visualisation-and-interactive/ai-governance-database/); Jobin, Anna, Marcello Ienca, and Effy Vayena. "The Global Landscape of AI Ethics Guidelines." Nature Machine Intelligence 1, no. 9 (September 1, 2019): 389–99; Zeng, Y., Lu, E., & Huangfu, C. (2018). Linking Artificial Intelligence Principles. AAAI Workshop on Artificial Intelligence Safety (AAAI-Safe AI 2019), 2019arXiv preprint arXiv:1812.04814;https://www.accessnow.org/cms/assets/uploads/2018/08/The-Toronto-Declaration_ENG_08-2018.pdf;https://www.nesta.org.uk/blog/10-principles-for-public-sector-use-of-algorithmic-decision-making/.

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STATISTICAL APPENDIX. READINESS FOR FRONTIER TECHNOLOGIES INDEX

A. RESULTS OF THE READINESS FOR FRONTIER TECHNOLOGIES INDEX

The index yielded results for 158 countries with the United States, Switzerland and the United Kingdom receiving the highest scores on a scale of 0 to 1 (Table 1). Based on their rankings, countries are placed within one of four 25-percentile score groups: low, lower-middle, upper-middle, and high values of the index.

Table 1
Index score ranking

Country name	Total score	Total rank-ing	Score group	ICT ranking	Skills ranking	R&D ranking	Industry ranking	Finance ranking
United States of America	1.00	1	High	14	17	2	20	2
Switzerland	0.97	2	High	7	13	13	3	3
United Kingdom	0.96	3	High	17	12	6	11	14
Sweden	0.96	4	High	1	7	16	15	16
Singapore	0.95	5	High	4	9	18	4	18
Netherlands	0.95	6	High	6	10	15	8	23
Korea, Republic of	0.93	7	High	19	27	3	9	8
Ireland	0.92	8	High	24	6	21	1	87
Germany	0.92	9	High	23	16	5	10	39
Denmark	0.92	10	High	2	4	25	21	5
Belgium	0.90	11	High	10	3	24	17	48
Australia	0.90	12	High	31	1	12	61	12
France	0.89	13	High	22	19	8	13	24
Canada	0.89	14	High	13	21	9	27	17
China, Hong Kong SAR	0.88	15	High	12	31	22	6	1
Luxembourg	0.87	16	High	3	18	36	25	21
Finland	0.87	17	High	18	11	20	24	28
Japan	0.87	18	High	9	49	7	14	4
Norway	0.86	19	High	5	5	28	50	10
Israel	0.84	20	High	48	14	19	5	51
Spain	0.83	21	High	16	22	14	39	25
Austria	0.79	22	High	26	26	23	26	36
New Zealand	0.79	23	High	8	8	41	70	7
Italy	0.76	24	High	52	32	10	30	44
China	0.76	25	High	99	96	1	7	6
Czechia	0.75	26	High	30	23	32	18	72
Russian Federation	0.75	27	High	39	28	11	66	45
Poland	0.73	28	High	32	30	30	32	70
Estonia	0.72	29	High	15	20	59	31	61
Iceland	0.71	30	High	11	2	69	101	30
Malaysia	0.71	31	High	29	65	33	12	19

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Portugal	0.71	32	High	35	33	31	49	27
Slovenia	0.69	33	High	28	15	62	29	84
Cyprus	0.69	34	High	43	44	43	36	11
Malta	0.69	35	High	33	25	73	19	43
Slovakia	0.69	36	High	21	47	44	23	59
Hungary	0.67	37	High	27	43	48	16	99
Greece	0.66	38	High	51	34	35	54	32
Lithuania	0.65	39	High	25	24	54	48	88
Latvia	0.65	40	High	20	29	75	37	92
Brazil	0.65	41	Upper-middle	73	53	17	42	60
United Arab Emirates	0.63	42	Upper-middle	34	57	38	44	38
India	0.62	43	Upper-middle	93	108	4	28	76
Philippines	0.60	44	Upper-middle	76	88	46	2	52
Romania	0.60	45	Upper-middle	44	70	34	38	115
Thailand	0.59	46	Upper-middle	57	91	40	34	9
Serbia	0.59	47	Upper-middle	38	52	55	46	86
Barbados	0.58	48	Upper-middle	36	46	79	56	37
Chile	0.57	49	Upper-middle	61	45	45	109	20
Saudi Arabia	0.57	50	Upper-middle	56	41	26	129	69
Bulgaria	0.57	51	Upper-middle	53	48	65	41	73
Croatia	0.56	52	Upper-middle	46	39	76	47	66
Ukraine	0.56	53	Upper-middle	66	40	47	58	97
South Africa	0.55	54	Upper-middle	69	84	39	71	13
Turkey	0.55	55	Upper-middle	75	63	27	78	49
Bahrain	0.54	56	Upper-middle	40	59	93	69	46
Mexico	0.54	57	Upper-middle	68	83	29	33	96
Kuwait	0.53	58	Upper-middle	49	81	84	65	31
Belarus	0.53	59	Upper-middle	45	35	91	63	109
Tunisia	0.51	60	Upper-middle	80	62	61	45	50
Costa Rica	0.51	61	Upper-middle	64	55	100	35	57
Kazakhstan	0.50	62	Upper-middle	62	42	56	75	114
Lebanon	0.50	63	Upper-middle	85	60	63	72	22
Jordan	0.50	64	Upper-middle	72	77	52	55	41
Argentina	0.49	65	Upper-middle	81	38	51	87	138
Viet Nam	0.49	66	Upper-middle	74	111	66	22	15
Panama	0.49	67	Upper-middle	65	90	72	40	34
Uruguay	0.47	68	Upper-middle	58	50	80	73	110
Brunei Darussalam	0.47	69	Upper-middle	50	36	93	111	95
Montenegro	0.47	70	Upper-middle	55	37	111	97	78
Iran (Islamic Republic of)	0.46	71	Upper-middle	82	74	37	130	53
Qatar	0.46	72	Upper-middle	42	100	57	137	42
North Macedonia	0.46	73	Upper-middle	54	68	98	62	75
Oman	0.45	74	Upper-middle	60	87	77	88	47
Trinidad and Tobago	0.45	75	Upper-middle	41	71	121	92	90

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Morocco	0.45	76	Upper-middle	78	120	50	57	35
Mauritius	0.45	77	Upper-middle	83	58	94	74	40
Colombia	0.44	78	Upper-middle	88	79	53	99	77
Georgia	0.44	79	Upper-middle	71	56	87	81	56
Bosnia and Herzegovina	0.43	80	Lower-middle	63	76	85	84	64
Republic of Moldova	0.41	81	Lower-middle	47	98	88	83	121
Indonesia	0.40	82	Lower-middle	101	113	49	51	91
Armenia	0.39	83	Lower-middle	77	69	103	105	67
Bahamas	0.39	84	Lower-middle	37	73	143	126	74
Albania	0.38	85	Lower-middle	59	78	105	106	98
Sri Lanka	0.38	86	Lower-middle	95	85	71	102	81
Egypt	0.38	87	Lower-middle	117	67	42	100	116
Fiji	0.37	88	Lower-middle	91	64	115	104	29
Peru	0.36	89	Lower-middle	102	72	70	134	83
Ecuador	0.34	90	Lower-middle	90	94	64	141	94
Namibia	0.34	91	Lower-middle	97	109	101	59	58
Suriname	0.34	92	Lower-middle	98	66	140	79	112
Saint Lucia	0.34	93	Lower-middle	84	75	153	93	62
Gabon	0.33	94	Lower-middle	103	99	133	43	143
Dominican Republic	0.33	95	Lower-middle	79	101	133	68	111
Jamaica	0.32	96	Lower-middle	67	93	120	118	101
Belize	0.32	97	Lower-middle	87	86	136	120	68
Algeria	0.31	98	Lower-middle	120	80	68	152	119
Venezuela (Bolivarian Rep. of)	0.30	99	Lower-middle	96	61	95	156	105
Azerbaijan	0.30	100	Lower-middle	70	95	90	154	128
Cabo Verde	0.29	101	Lower-middle	92	107	153	82	63
Paraguay	0.29	102	Lower-middle	89	105	115	135	85
Ghana	0.28	103	Lower-middle	106	121	81	90	148
Guatemala	0.28	104	Lower-middle	86	132	115	77	100
Kenya	0.28	105	Lower-middle	108	123	78	89	108
El Salvador	0.27	106	Lower-middle	113	116	127	64	71
Eswatini	0.27	107	Lower-middle	119	115	127	53	129
Guyana	0.27	108	Lower-middle	105	114	153	91	82
Nepal	0.26	109	Lower-middle	110	128	108	140	33
Mongolia	0.26	110	Lower-middle	132	51	140	150	65
Botswana	0.26	111	Lower-middle	111	104	109	114	102
Bangladesh	0.26	112	Lower-middle	133	130	58	121	80
Cambodia	0.26	113	Lower-middle	109	122	140	95	26
Maldives	0.25	114	Lower-middle	100	54	153	153	103
Kyrgyzstan	0.25	115	Lower-middle	112	97	127	98	120
Bolivia (Plurinational State of)	0.24	116	Lower-middle	116	92	127	151	54
Libya	0.24	117	Lower-middle	135	89	106	132	135

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Senegal	0.24	118	Lower-middle	107	137	82	112	107
Papua New Guinea	0.23	119	Low	136	134	111	60	130
Saint Vincent and the Grenadines	0.22	120	Low	123	82	153	146	79
Myanmar	0.22	121	Low	104	144	83	94	118
Honduras	0.20	122	Low	118	133	115	133	55
Pakistan	0.20	123	Low	145	146	60	96	132
Nigeria	0.20	124	Low	124	106	74	155	149
Nicaragua	0.19	125	Low	129	112	140	139	89
Iraq	0.19	126	Low	115	103	67	158	153
Lao People's Dem. Rep.	0.19	127	Low	127	129	133	52	127
Uganda	0.18	128	Low	125	131	89	110	137
Togo	0.17	129	Low	139	126	140	103	93
Madagascar	0.16	130	Low	94	143	127	115	145
Côte d'Ivoire	0.16	131	Low	114	148	118	113	113
Cameroon	0.15	132	Low	144	118	103	123	140
Rwanda	0.15	133	Low	128	136	112	107	125
Zambia	0.15	134	Low	121	119	118	148	141
Congo	0.13	135	Low	157	125	122	80	136
Zimbabwe	0.13	136	Low	126	140	96	138	142
Malawi	0.12	137	Low	142	139	127	85	150
United Republic of Tanzania	0.12	138	Low	131	154	98	86	144
Benin	0.12	139	Low	150	124	118	122	122
Sao Tome and Principe	0.12	140	Low	141	110	153	128	123
Mali	0.11	141	Low	146	157	127	76	117
Comoros	0.10	142	Low	137	127	153	117	139
Tajikistan	0.10	143	Low	148	117	133	119	147
Timor-Leste	0.09	144	Low	155	102	146	127	151
Burundi	0.08	145	Low	138	135	146	142	133
Djibouti	0.07	146	Low	122	158	153	108	126
Mauritania	0.07	147	Low	156	151	133	124	106
Burkina Faso	0.06	148	Low	151	156	127	145	104
Mozambique	0.06	149	Low	140	149	140	147	124
Ethiopia	0.05	150	Low	152	155	86	144	134
Sierra Leone	0.05	151	Low	153	145	146	67	156
Afghanistan	0.05	152	Low	149	141	107	131	158
Guinea	0.05	153	Low	147	152	153	116	152
Haiti	0.04	154	Low	134	147	153	149	131
Sudan	0.04	155	Low	130	153	104	157	146
Yemen	0.03	156	Low	158	142	98	143	157
Gambia	0.00	157	Low	143	150	146	136	154
Dem. Rep. of the Congo	0.00	158	Low	154	138	153	125	155
Average score	**0.44**							

Source: UNCTAD.

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B. READINESS FOR FRONTIER TECHNOLOGIES INDEX RESULTS BY SELECTED GROUPS

Table 2
Index results - Small Island Developing States (SIDS)

Country name	Total score	Total ranking	Score group	ICT ranking	Skills ranking	R&D ranking	Industry ranking	Finance ranking
Barbados	0.58	48	Upper-middle	36	46	79	56	37
Trinidad and Tobago	0.45	75	Upper-middle	41	71	121	92	90
Mauritius	0.45	77	Upper-middle	83	58	94	74	40
Bahamas	0.39	84	Lower-middle	37	73	143	126	74
Fiji	0.37	88	Lower-middle	91	64	115	104	29
Saint Lucia	0.34	93	Lower-middle	84	75	153	93	62
Jamaica	0.32	96	Lower-middle	67	93	120	118	101
Cabo Verde	0.29	101	Lower-middle	92	107	153	82	63
Maldives	0.25	114	Lower-middle	100	54	153	153	103
Saint Vincent and the Grenadines	0.22	120	Low	123	82	153	146	79
Sao Tome and Prin-cipe	0.12	140	Low	141	110	153	128	123
Comoros	0.10	142	Low	137	127	153	117	139
Timor-Leste	0.09	144	Low	155	102	146	127	151
Average score	**0.31**							

Source: UNCTAD.

Table 3
Index results - Least Developed Countries (LDCs)

Country name	Total score	Total ranking	Score group	ICT ranking	Skills ranking	R&D ranking	Industry ranking	Finance ranking
Nepal	0.26	109	Lower-middle	110	128	108	140	33
Bangladesh	0.26	112	Lower-middle	133	130	58	121	80
Cambodia	0.26	113	Lower-middle	109	122	140	95	26
Senegal	0.24	118	Lower-middle	107	137	82	112	107
Myanmar	0.22	121	Low	104	144	83	94	118
Lao People's Dem. Rep.	0.19	127	Low	127	129	133	52	127
Uganda	0.18	128	Low	125	131	89	110	137
Togo	0.17	129	Low	139	126	140	103	93
Madagascar	0.16	130	Low	94	143	127	115	145
Rwanda	0.15	133	Low	128	136	112	107	125
Zambia	0.15	134	Low	121	119	118	148	141
Malawi	0.12	137	Low	142	139	127	85	150
United Republic of Tanzania	0.12	138	Low	131	154	98	86	144

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Benin	0.12	139	Low	150	124	118	122	122
Sao Tome and Principe	0.12	140	Low	141	110	153	128	123
Mali	0.11	141	Low	146	157	127	76	117
Comoros	0.10	142	Low	137	127	153	117	139
Timor-Leste	0.09	144	Low	155	102	146	127	151
Burundi	0.08	145	Low	138	135	146	142	133
Djibouti	0.07	146	Low	122	158	153	108	126
Mauritania	0.07	147	Low	156	151	133	124	106
Burkina Faso	0.06	148	Low	151	156	127	145	104
Mozambique	0.06	149	Low	140	149	140	147	124
Ethiopia	0.05	150	Low	152	155	86	144	134
Sierra Leone	0.05	151	Low	153	145	146	67	156
Afghanistan	0.05	152	Low	149	141	107	131	158
Guinea	0.05	153	Low	147	152	153	116	152
Haiti	0.04	154	Low	134	147	153	149	131
Sudan	0.04	155	Low	130	153	104	157	146
Yemen	0.03	156	Low	158	142	98	143	157
Gambia	0.00	157	Low	143	150	146	136	154
Dem. Rep. of the Congo	0.00	158	Low	154	138	153	125	155
Average score	**0.12**							

Source: UNCTAD.

Table 4
Index results - Landlocked Developing Countries (LLDCs)

Country name	Total score	Total ranking	Score group	ICT ranking	Skills ranking	R&D ranking	Industry ranking	Finance ranking
Kazakhstan	0.50	62	Upper-middle	62	42	56	75	114
North Macedonia	0.46	73	Upper-middle	54	68	98	62	75
Republic of Moldova	0.41	81	Lower-middle	47	98	88	83	121
Armenia	0.39	83	Lower-middle	77	69	103	105	67
Azerbaijan	0.30	100	Lower-middle	70	95	90	154	128
Paraguay	0.29	102	Lower-middle	89	105	115	135	85
Eswatini	0.27	107	Lower-middle	119	115	127	53	129
Nepal	0.26	109	Lower-middle	110	128	108	140	33
Mongolia	0.26	110	Lower-middle	132	51	140	150	65
Botswana	0.26	111	Lower-middle	111	104	109	114	102
Kyrgyzstan	0.25	115	Lower-middle	112	97	127	98	120
Bolivia (Plurinational State of)	0.24	116	Lower-middle	116	92	127	151	54
Lao People's Dem. Rep.	0.19	127	Low	127	129	133	52	127
Uganda	0.18	128	Low	125	131	89	110	137
Rwanda	0.15	133	Low	128	136	112	107	125
Zambia	0.15	134	Low	121	119	118	148	141

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Zimbabwe	0.13	136	Low	126	140	96	138	142
Malawi	0.12	137	Low	142	139	127	85	150
Mali	0.11	141	Low	146	157	127	76	117
Tajikistan	0.10	143	Low	148	117	133	119	147
Burundi	0.08	145	Low	138	135	146	142	133
Burkina Faso	0.06	148	Low	151	156	127	145	104
Ethiopia	0.05	150	Low	152	155	86	144	134
Afghanistan	0.05	152	Low	149	141	107	131	158
Average score	**0.22**							

Source: UNCTAD.

Table 5
Index results - Sub-Saharan Africa

Country name	Total score	Total ranking	Score group	ICT ranking	Skills ranking	R&D ranking	Industry ranking	Finance ranking
South Africa	0.55	54	Upper-middle	69	84	39	71	13
Mauritius	0.45	77	Upper-middle	83	58	94	74	40
Namibia	0.34	91	Lower-middle	97	109	101	59	58
Gabon	0.33	94	Lower-middle	103	99	133	43	143
Cabo Verde	0.29	101	Lower-middle	92	107	153	82	63
Ghana	0.28	103	Lower-middle	106	121	81	90	148
Kenya	0.28	105	Lower-middle	108	123	78	89	108
Eswatini	0.27	107	Lower-middle	119	115	127	53	129
Botswana	0.26	111	Lower-middle	111	104	109	114	102
Senegal	0.24	118	Lower-middle	107	137	82	112	107
Nigeria	0.20	124	Low	124	106	74	155	149
Uganda	0.18	128	Low	125	131	89	110	137
Togo	0.17	129	Low	139	126	140	103	93
Madagascar	0.16	130	Low	94	143	127	115	145
Côte d'Ivoire	0.16	131	Low	114	148	118	113	113
Cameroon	0.15	132	Low	144	118	103	123	140
Rwanda	0.15	133	Low	128	136	112	107	125
Zambia	0.15	134	Low	121	119	118	148	141
Congo	0.13	135	Low	157	125	122	80	136
Zimbabwe	0.13	136	Low	126	140	96	138	142
Malawi	0.12	137	Low	142	139	127	85	150
United Republic of Tanzania	0.12	138	Low	131	154	98	86	144
Benin	0.12	139	Low	150	124	118	122	122
Sao Tome and Principe	0.12	140	Low	141	110	153	128	123
Mali	0.11	141	Low	146	157	127	76	117
Comoros	0.10	142	Low	137	127	153	117	139
Burundi	0.08	145	Low	138	135	146	142	133
Djibouti	0.07	146	Low	122	158	153	108	126

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Mauritania	0.07	147	Low	156	151	133	124	106
Burkina Faso	0.06	148	Low	151	156	127	145	104
Mozambique	0.06	149	Low	140	149	140	147	124
Ethiopia	0.05	150	Low	152	155	86	144	134
Sierra Leone	0.05	151	Low	153	145	146	67	156
Guinea	0.05	153	Low	147	152	153	116	152
Gambia	0.00	157	Low	143	150	146	136	154
Dem. Rep. of the Congo	0.00	158	Low	154	138	153	125	155
Average score	**0.17**							

Source: UNCTAD.

C. TECHNICAL NOTE – READINESS FOR FRONTIER TECHNOLOGIES INDEX

As a result of a review of the literature, UNCTAD's analytical and technical cooperation work, consultation with experts within and outside UNCTAD, as well as taking into consideration data availability, five building blocks were selected for the index to measure the capacity to use, adopt and adapt frontier technologies: ICT deployment, skills, R&D activity, industry activity and access to finance. The five building blocks and the selected indicators are as follows (Table 6):

1. **ICT deployment** – This is the level of ICT infrastructure. Using, adopting and adapting frontier technologies requires sufficient ICT infrastructure, especially since AI, IoT, big data and blockchain are internet-based technologies. Two aspects of ICT infrastructure need to be considered: the prevalence to ensure that everyone has access and that no one is left behind; and the quality of infrastructure that allows for more advanced and efficient use. For these purposes, internet users as a percentage of the population captures the prevalence of internet infrastructure, while the mean download speed measures the quality of internet connection.

2. **Skills** – Using, adopting and adapting frontier technologies needs people equipped with relevant skills. These may be advanced but are generally lower than those required to originate the technologies. Two types of skills need to be considered: skills acquired through education, and skills acquired in the workplace through practical training or learning-by-doing. The overall educational attainment of the population is measured through expected years of schooling, while the skill level in the labour market is measured by the extent of high-skill employment – defined by the ILO as the sum of managers, professionals and technicians and associate professionals following the International Standard Classification of Occupations (ISCO). These indicators need to be interpreted with caution, especially in developing countries, because of the emigration of highly trained or skilled people, the "brain drain", as a result of which the actual skill level could be lower than the official estimate.

3. **R&D activity –** R&D activity is needed not just for the production of frontier technologies, but also for adoption and adaption, as these technologies often require adjustment or modification for local use. R&D activities are measured using the number of publications and patents filed on the 11 frontier technologies in a country. The publication and patent search queries used are the same as shown in the Technical note in Annex B, the only difference being the year of interest – a single year for the index instead of 1996-2018. The countries of publication of authors and patent assignees were analysed. It should be noted that, especially in developing countries, there are informal R&D activities that do not result in a publication or patent so the R&D scores might not reflect the actual scale of activities.

4. **Industry activity** – This building block aims to capture ongoing activities in an industry related to the use, adoption and adaption of frontier technologies. It considers three sectors that are early

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adopters: manufacturing, with high-tech manufacturing as the frontrunner; finance; and ICT, which tends to interact with other technologies. Then it uses export data, on high-technology manufactures, as well as on digitally deliverable services which cover both finance and ICT. However, especially in developing countries, activities are also undertaken by firms in the informal sector – which are often outside official statistics. The scores from these countries could therefore be lower than the actual activity.

5. **Access to finance** – This assesses the availability of finance to the private sector. Better access to finance could accelerate the use, adoption and adaption of frontier technologies. For this purpose, domestic credit to the private sector as a percentage of GDP was selected as part of the index. This indicator measures resources provided by financial corporations such as finance and leasing companies, money lenders, insurance corporations, pension funds and foreign exchange companies. It also includes various financial instruments including loans, purchases of non-equity securities, and trade credits and other accounts receivable. However, there could also be other, unconventional financing providers or financial instruments that are not covered sufficiently by this indicator.

Table 6
Indicators included in the index

Category	Indicator name	Source	No. of countries
ICT deployment	Internet users (per cent of population)	ITU	210
ICT deployment	Mean download speed (Mbps)	M-Lab	194
Skills	Expected years of schooling	UNDP	191
Skills	High-skill employment (% of working population)	ILO	185
R&D activity	Number of scientific publications on frontier technologies	SCOPUS	234
R&D activity	Number of patents filed on frontier technologies	PatSeer	234
Industry activity	High-technology manufactures exports (% of total merchandise trade)	UNCTAD	216
Industry activity	Digitally deliverable services exports (% of total service trade)	UNCTAD	186
Access to finance	Domestic credit to private sector (% of GDP)	WB/IMF/OECD	213

Source: UNCTAD.

The selection of building blocks and underlying indicators was constrained by data availability. As the objective of this index is to cover as many countries as possible, especially developing countries, every effort was made to find indicators with the widest possible country coverage. In addition, in order to ensure that the chosen indicators are directly linked to the building blocks and the final index of interest, certain types of indicator were avoided. These included perception indicators such as policy effectiveness for which it is difficult to ensure objectivity or cross-country comparability, and input indicators whose effects may not be as straightforward as those of output indicators. Based on these considerations, some of the indicators excluded are indicated in Table 7.

The underlying indicator data were then statistically manipulated to form the index. Firstly, the data were imputed using the cold deck imputation method (i.e. retroactively filling the missing values with the latest values available from the same country). It should be noted that as this index deals with frontier technologies whose development is a recent phenomenon and happening rapidly, cold deck imputation could potentially understate a country's performance in the year of interest since it could still be at the initial phase of technological development. An alternative imputation method, such as multivariate imputation, was considered, however, the variables were unlikely to be suitable explanatory

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Table 7
Selected indicators not included in the index

Category	Indicator name	Source	# of countries	Reason
Skills	Output per worker (in PPP US$ 2011)	ILO	187	4)
Skills	Percentage of graduates from STEM programmes in tertiary education	UNESCO	124	1)
Skills	PISA score in mathematics	UNDP	129	1)
Skills	PISA score in science	UNDP	129	1)
Skills	Number of employees in high-tech and medium-high-tech sector (% of total employees in manufacturing)	UNIDO	101	1)
Skills	Researchers in R&D (per million people)	UNESCO	153	1)
Skills	Quality of math and science education	WEF	151	1) + 2)
Skills	Country capacity to retain talent, 1-7 (best)	WEF	149	1) + 2)
Skills	Country capacity to attract talent, 1-7 (best)	WEF	149	1) + 2)
Skills	Digital skills among population	WEF	134	1) + 2)
Skills	Proportion of youth and adults with ICT skills (%)	UNESCO	58	1)
R&D activity	Research and development expenditure (% of GDP)	UNESCO	108	1) + 3)
Industry activity	Medium and high-tech Industry (including construction) (% manufacturing value added)	UNIDO	147	1)
Industry activity	ICT Service Exports (% Of Service Exports, BoP)	WITS	165	1)
Industry activity	Insurance and Financial Services (% Of Commercial Service Imports)	WITS	165	1)
Access to finance	Venture capital availability, 1-7 (best)	WEF	151	1) + 2)
Access to finance	Ease of access to loans, 1-7 (best)	WEF	151	1) + 2)
Policy effectiveness	CPIA business regulatory environment rating (1=low to 6=high)	WB	113	1) + 2)
Policy effectiveness	CPIA quality of public administration rating (1=low to 6=high)	WB	113	1) + 2)
Policy effectiveness	Effectiveness of anti-monopoly policy, 1-7 (best)	WEF	150	1) + 2)

Source: UNCTAD.
Notes: The numbers listed in the column "Reason" mean: 1) limited country coverage, 2) perception indicator, 3) input indicator and 4) output depends not only on skills.

variables to impute missing values hence this method was not used. Therefore, imputation is one area that could potentially be further improved in future versions of the index. Following imputation, countries with missing values as well as those with extreme outlier values were removed from the dataset. Then, variables that had very skewed distributions (both p-value for skewness and p-value for joint skewness and kurtosis were 0) were transformed using a log transformation. After that, the Z-score standardization was conducted using the following formula:

$$X_{standardized} = \frac{x-\mu}{\sigma}$$

Where:

X is a value to be standardized;

μ is the mean of the population;

σ is the standard deviation of the population.

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The standardized value of each indicator was then normalized to fall between the range of 0 to 1 using the formula below:

$$X_{normalized} = \frac{x\text{-}Min}{Max\text{-}Min}$$

Where:

X is a Z-score standardized score to be normalized;

Max is the largest score in the population;

Min is the smallest score in the population.

After these procedures, a principal component analysis (PCA) was conducted, mainly because of its advantage to remove correlated features among indicators and reduce overfitting. Based on the variance explained criteria method, PCA found that three principal components could retain more than 80 per cent of the variation. Thus, the final index was derived by assigning the weights generated by PCA with rotation to the three principal components, and then standardized and normalized to fall within the range of 0 to 1 (Table 8).

Table 8
Breakdown of principal components

Variable	PC1	PC2	PC3	Unexplained
ICT (access)	0.5370	-0.0358	-0.0164	.1439
ICT (speed) (log)	0.3302	0.2022	-0.0428	.2062
Skills (education)	0.4827	0.0231	-0.0273	.1843
Skills (labour)	0.5643	-0.0995	0.1509	.1128
R&D (publication) (log)	-0.0820	0.5501	0.0888	.2162
R&D (patent) (log)	-0.0515	0.5285	0.1599	.1516
Industry (high-tech) (log)	0.0003	0.4988	-0.0791	.2824
Industry (digital)	0.0261	0.0288	0.9240	.05245
Access to finance (log)	0.2025	0.3403	-0.2844	.2564

Source: UNCTAD.

Separately, PCA was also performed on each building block of the index to derive the score and country ranking within each building block. Here again, PCA used the minimum number of principal components that could retain more than 80 per cent of the variation. PCA was not conducted for the access to finance building block as it contained only one indicator.

$$ICT\ deployment = (\text{PC1})_{standarized\ \&\ normalized}$$

$$Skills = (\text{PC1})_{standarized\ \&\ normalized}$$

$$R\&D\ activity = (\text{PC1})_{standarized\ \&\ normalized}$$

$$Industry\ activity = (0.6566)*(\text{PC1}) + (0.3434)*(\text{PC2})_{standarized\ \&\ normalized}$$

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