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World Economic and Social Survey 2018:

Frontier technologies for sustainable development

Overview*

Summary

World Economic and Social Survey 2018 reviews the advances in frontier technologies — including automation, robotics, renewable energy technologies, electric vehicles, biotechnologies and artificial intelligence — and analyses their economic, social and environmental impact. These technologies present immense potentials for the 2030 Agenda for Sustainable Development, fostering growth, prosperity and environmental sustainability. They also pose significant risks of unemployment, underemployment and rising income and wealth inequality and raise new ethical and moral concerns.

The *Survey* identifies policy measures at national levels with the capacity to both maximize the potential of these technologies and mitigate their risks, thereby striking a balance among economic efficiency, equity and ethical considerations. It makes a case for providing incentives for the development, diffusion and adoption of appropriate and enabling technologies, while increasing investments in education, skills development and social protection.

Recognizing that no nation can alone manage the impact of frontier technologies, which transcend sectoral and national boundaries, the *Survey* calls for global collective action to confront the challenge of technological breakthroughs so as to ensure that they benefit all and that no one is left behind. It highlights the imperatives of greater international cooperation, particularly in identifying and designating the technologies most needed for sustainable development as global public goods, reflecting a commitment to shared and differentiated responsibilities among all nations.

* The present overview summarizes the key findings presented in *World Economic and Social Survey 2018*.

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Introduction

The 2030 Agenda for Sustainable Development[1] unites humanity in the pursuit of a common aspiration and a new path of action. The 17 Sustainable Development Goals under the Agenda are universal and mutually reinforcing. The achievement of these ambitious goals — while leaving no one behind — will require new development strategies and innovative resource mobilization. Emerging technologies have the potential to provide additional impetus for advancing the Sustainable Development Goals. *World Economic and Social Survey 2018* explores how certain new technologies[2] can foster or hinder sustainable development and identifies policy measures that can expand potential benefits and mitigate any potential adverse effects on sustainable development.

The Sustainable Development Goals are for "people, planet and prosperity". The goals of ending hunger, reducing maternal and infant mortality, and ending epidemics of AIDS, malaria and tuberculosis will require the widespread application of technological breakthroughs in genetics and nanomedicine. Creating decent jobs, building resilient infrastructure and promoting sustainable industrialization will entail automation, 3D printing and artificial intelligence (AI). Renewable energy technologies (RETs) will expand access to affordable and reliable energy sources, while electric vehicles will potentially reduce emissions and help combat climate change. The *Survey* recognizes that a number of developed countries and a few large developing countries are leading innovation in frontier technologies, while many developing countries, particularly least developed countries, landlocked developing countries and small island developing States,[3] continue to face daunting challenges in innovation and adoption of new technologies. Achieving sustainable development will require greater international cooperation for the generation, diffusion, adoption and adaptation of frontier technologies, reflecting shared and differentiated responsibilities among all countries.

Technology has been a driver of progress and prosperity throughout human history. While technological change in the past has been incremental, often requiring decades if not centuries for diffusion and adoption, the structural and behavioural changes brought about by many frontier technologies are often rapid and widespread. The *Survey* recognizes the rapid pace of diffusion of frontier technologies, transcending sectors and national boundaries, as both an advantage and a challenge.

Frontier technologies encompass, inter alia, advanced materials such as graphene and biodegradable plastics, new products and devices such as electrical vehicles and solar photovoltaic (PV) panels, scientific breakthroughs in gene editing and nanomedicine, proliferations of crowd-based platforms, and new applications and tools, including the blockchain, 3D printing, robotics and AI. Hundreds and thousands of individual patents form the backbone of these products, services and tools.

These technologies are often interconnected and interdependent: advances in one are likely to impact many others. Just as rapid improvements in transistor capacities enabled faster and smaller devices, advances in AI will, for example, make many frontier technologies smarter and more efficient.

The *Survey* underscores that technological change is seldom neutral and costless. Indeed, previous industrial revolutions, while increasing efficiency and

[1] General Assembly resolution 70/1 of 25 September 2015.

[2] The terms "new technologies", "emerging technologies", "frontier technologies" and "technological breakthroughs" are used interchangeably in the overview.

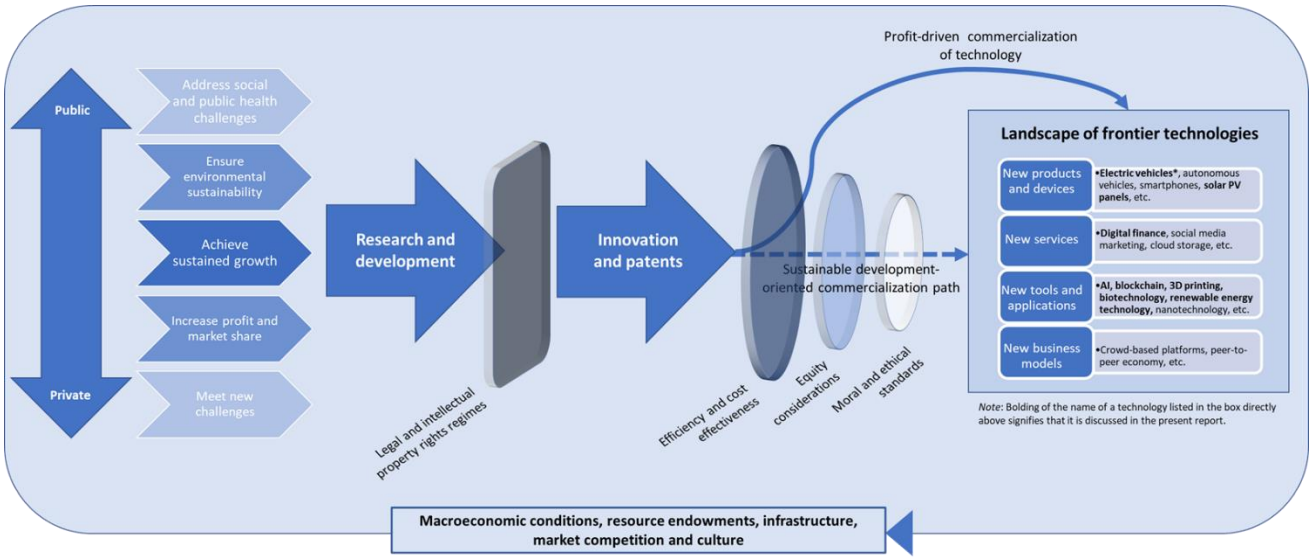
[3] In this overview, countries belonging to any of these groups are referred to as countries in special situations.

prosperity, came with huge environmental costs. They also contributed to greater income inequality across countries and regions. Advances in a frontier technology — automation, for example — can benefit capital owners but disadvantage workers and exacerbate already existing inequalities in income distribution. They can have significant spillovers and externalities within and across countries, imposing painful adjustment costs on different population groups. Frontier technologies present additional challenges related to ethics and morality, which can potentially undermine trust, cohesion, tolerance, peace and stability. In this regard, the *Survey* makes a case for promoting ethical standards and effective and accountable institutions to guide progress in many frontier technologies and promote peaceful and inclusive societies.

Technological advances during the past three centuries enabled a few societies to leap forward, while others lagged, as attested by the great technological divide among countries that exists today. Many developing countries have yet to fully utilize the technological breakthroughs of the past. The *Survey* recognizes the urgent need to bridge the persistent technological divide among developed and many developing countries. While the relative ease of diffusion and replication of frontier technologies presents opportunities for leapfrogging, reducing technological divides among many developed and less developed countries will require significant investments in human and physical infrastructures in many developing countries.

National innovation systems play a key role in bringing new technologies to the market. There is no one-size-fits-all model of a national innovation system, however. Both public and private sector entities play varying and complementary roles, which are dependent on a country's development level and market structure. The *Survey* recognizes the need for aligning and balancing efficiency and cost effectiveness with equity considerations and ethical standards so as to bring appropriate, sustainable development-oriented technologies to the marketplace (see figure I). National innovation systems, underpinned by appropriate policies, guidelines and incentives, can ensure this balance. Developing countries would benefit considerably from a national innovation system that enables local firms to adopt the technologies that are most critical to advancing their sustainable development priorities. Well-targeted investments in research and development (R&D) can enable these countries to overcome technological divides and leapfrog to appropriate frontier technologies.

Figure I
The development process for frontier technologies



Source: Department of Economic and Social Affairs of the United Nations Secretariat (UN/DESA).

Note: The immense scope of frontier technologies and the rapid pace of their diffusion across national boundaries — affecting efficiency, equity and ethical standards — demand global collective action. While national responsibilities remain paramount, no nation can alone harness the full potential of emerging technologies and mitigate the associated risks. The *Survey* highlights the imperative of effective international cooperation for managing advances in frontier technologies. Such cooperation is clearly needed to ensure that advances in frontier technology meet universal ethical and moral standards and that competition in the technology sector is fair. New standards of corporate governance, corporate social responsibility and consumer protection can ensure that frontier technologies promote equity and social justice. While intellectual property rights (IPR) regimes play an important role in spurring innovation, there is a need for greater flexibility in the area of intellectual property rights to facilitate diffusion of technologies, especially technologies that can foster sustainable development. Greater international tax cooperation can provide a vital new source of revenues from the digital economy to provide social protection and a basic minimum income, especially to those adversely affected by frontier technologies.

I. Frontier technologies: harbingers of future prosperity

Technologies have played a transformative role in human history. They have saved the lives of millions, improved education outcomes, increased communication and connectivity, and lowered costs of ever better goods and services. The emergence of the printing press facilitated information sharing across time and space and shaped global enlightenment. Railways, by expanding the reach of societies and commerce, created new national economies and geopolitical identities. The advent of television and the Internet reduced cultural distances, transforming not only communication and entertainment but the very nature of human interactions.

Yet, humanity still faces the daunting sustainable development challenge of securing food, health and education for all, while generating inclusive growth, ensuring sustainable use of natural resources, combating climate change and creating peaceful societies.

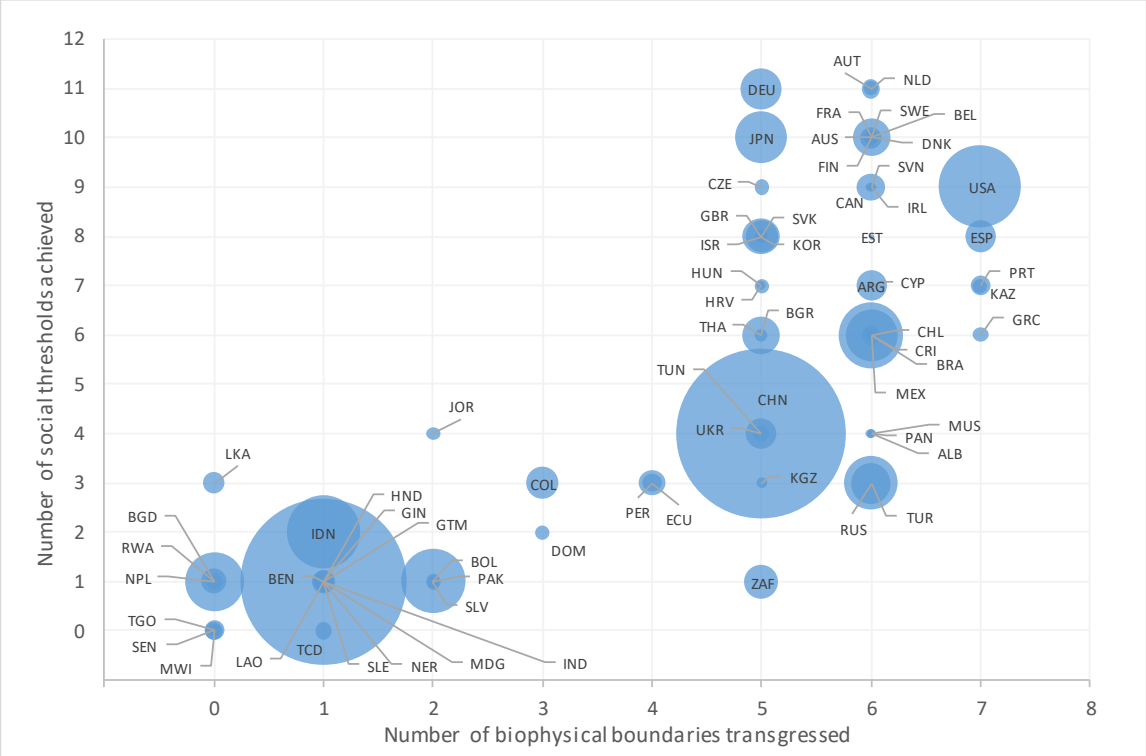
Prosperity in the past came at a high cost

In the past, progress and prosperity came at a price: transgression of the biophysical boundaries of water use, CO_2 emissions, biomass appropriation,[4] and phosphorus, nitrogen and other material and ecological footprints. Countries that

[4] The amount of biomass used in agriculture and forestry or lost owing to changes in land use.

made progress in achieving many socioeconomic goals — improved life satisfaction, expectation of a healthy life, nutrition, sanitation, access to energy, education, social support, equality, higher income and employment — also crossed a greater number of biophysical boundaries (see figure II). O'Neill and others (2018)[5] have found that achieving a greater number of development goals will require a level of resource use ranging from two to six times the sustainable level unless there are significant improvements in use of relevant technologies. Sustainability of the planet will hinge, critically, on the potential of frontier technologies to deliver prosperity and well-being without further transgression of biophysical boundaries.

Figure II
Biophysical boundaries transgressed versus social thresholds achieved, by country



Source: UN/DESA, based on data available at https://goodlife.leeds.ac.uk/download-data/, from Daniel W. O'Neill and others, "A good life for all within planetary boundaries", *Nature Sustainability*, vol. 1, No. 2 (February 2018), pp. 88–95. doi:10.1038/s41893-018-0021-4.
Note: Only 70 countries with complete data are included. Bubble size represents the total population of a country.

Potentials of frontier technologies

Frontier technologies hold an immense potential for improving human welfare. By expanding productive capacities and creating entirely new business models and industries, they have opened up new opportunities for growth, jobs and wealth creation and may also allow countries to achieve greater prosperity without transgressing biophysical boundaries. Technologies are encroaching upon areas in which the abilities of humans were once deemed indispensable, complementing

[5] Daniel W. O'Neill and others, "A good life for all within planetary boundaries", *Nature Sustainability*, vol. 1, No. 2 (February 2018), pp. 88–95. doi:10.1038/s41893-018-0021-4. Data available at https://goodlife.leeds.ac.uk/download-data/.

and/or substituting human intelligence just as machines substituted muscle power during the first industrial revolution. Advances in computing power, data storage and processing speed and in the use of algorithms for data analytics have enabled vast social networks, creating marketplaces for ideas and opportunities for billions.[6] The Internet of Things heralds a future of interconnected intelligent machines, with sensors that monitor the conditions of humans and machines, as well as their interactions. This will fundamentally transform consumption and production patterns.

AI promises better decision-making and enhanced economic growth. Drones offer opportunities for improving real-time monitoring of disaster zones and conflicts. In finance, digital technology is facilitating payments, savings, and the operation of credit and insurance markets, which has important implications for the poor and underserved.

Gene-level techniques allow manipulation of biological systems, including the human genome, and open the possibility for personalized precision medicine and an array of new treatments for diseases and epidemics. Biotechnology holds the potential for developing weather- and disease-resistant crop varieties, which would increase yields manyfold. Renewable energy technologies hold out great hopes for reducing emissions and environmental degradation. Advances in electricity conversion and storage may soon make renewable energy — solar, wind, ocean, hydro, geothermal and bioenergy — competitive with fossil fuels. Biobenign and biodegradable plastics present the possibility of drastically reducing plastics-related pollution, while enhancing resource efficiency. They may help realize the vision of a circular economy, where materials revert to their previous forms after having served the purpose for which they were transformed — with no waste and no pollution.

Frontier technologies may also reinforce each other, thereby offering greater efficiency gains. AI is already widely used in social media and crowd-based platforms, transcending sectoral barriers and transforming consumer behaviour. Targeted advertising, through learning from past purchases, likes and dislikes, is creating new demand. Through the gradual acquisition of further cognitive abilities, machine learning will become deeper and smarter. Efforts are already under way to enrich AI with common sense. A drone made with a 3D printer and equipped with AI may be capable of delivering precision medicine to a targeted population group or of spraying an “intelligent” quantity of seeds, fertilizers and pesticides by taking into account potential weather patterns and nutrient and moisture levels in the soil. AI, empowered by rapid advances in data storage, processing and transmission, may come to underpin all economic activities in the same way that the Internet has transformed economic and social interactions during the past two decades. Achieving the 2030 Agenda will require leveraging and managing advances in frontier technologies for inclusive, sustained and sustainable economic growth.

Frontier technologies and difficult trade-offs

Technological change always introduces difficult trade-offs between efficiency and equity. These trade-offs become particularly important in the context of the 2030 Agenda for Sustainable Development, which promises to leave no one behind. Many frontier technologies also raise difficult ethical and moral questions.

AI and robotics can complement or augment human capabilities, both mental and physical, and raise productivity to a new level. At the same time, they may substitute labour and reduce labour requirements drastically and thereby create

[6] See United Nations, Department of Economic and Social Affairs, “Global Sustainable Development Report 2016” (New York, July 2016). Available at https://sustainabledevelopment.un.org/index.php?page=view&type=400&nr=2328&menu=1515.

problems of underemployment and unemployment. Advanced automation will disproportionately affect workers directly in countries at the technology frontier and through trade channels in developing countries. While gene editing can lead to dramatic improvement in health care and longevity, it may create possibilities for further transmutation of the human species itself or open up a Pandora's box of dangerous pathogens. While social media networks may bring societies and communities together, user data can at the same time be harvested to promote certain viewpoints and sell products or weaponized to create social and political divides. Clear ownership rights and privacy protection can play a key role in preventing unintended or unauthorized use of data. Big data-based algorithms may perpetuate the biases of the underlying data and in doing so raise serious ethical questions regarding algorithmic decision-making. Self-learning algorithms, for example, may recognize and exploit a link between education level and home address or other demographic information, potentially reinforcing racial and other biases.

As these technologies move from research to application, they are transforming, if not disrupting, established business models and social norms. New share-economy business models are decentralizing capital and obliterating established relationships between employer and employee, with far-reaching consequences for labour income, social protection and income distribution. Some of these changes may be gradual or even imperceptible, while others can be sudden and obvious. The firms creating and exploiting many frontier technologies may also enjoy excessive market power, which can inhibit competition and future innovation.

The data economy transcends political and sectoral boundaries. Data generated in social media networks, or online retail and crowd-based platforms are critical inputs to machine learning and AI, and yet these data lack appropriate ownership rights. Furthermore, in the absence of clear ethical and regulatory guidelines, users in developing countries may become targets of the beta testing of many frontier technologies. In the data economy, individuals are both producers and consumers of data. Security and privacy of data therefore constitute an imperative for ensuring the integrity of the digital economy, which is being advanced by frontier technologies. A global consensus on data ownership, and appropriate ethical and legal guidelines, will be critically important for ensuring accountability and preventing excessive concentration of market power.

Frontier technologies may also widen the already existing technological divide both among countries and among different population groups within countries and further aggravate wealth and income inequality. Some countries and firms will easily adopt frontier technologies, while many others will continue to face challenges with respect to access to electricity, connectivity, water, sanitation and basic health services. AI and other technological advances may disproportionately benefit a few developed and large developing countries, and widen the technological divide.

In the past, technologies spread throughout countries and societies with a lag, which allowed policymakers to forestall their impact by putting in place appropriate policy measures designed to mitigate their adverse effects. At present, however, new technologies are diffused and adopted at breakneck speed in far-flung societies, often catching policymakers underprepared to deal with their impact. Given the global spillover effects of many of these technologies, international cooperation on managing their impact is not an option but an imperative.

II. Frontier technologies present both opportunities and challenges

Emerging technologies will impact societies and countries in diverse ways. They will affect many developed countries significantly, particularly those leading in innovation and adoption of those technologies. They will also have large spillover effects on the rest of the world, presenting both new development opportunities and new challenges, particularly to countries in special situations. Creating decent jobs and reining in inequality, while protecting the environment and ensuring social cohesion and stability, will be crucial considerations for countries at the technological frontier. Creating enabling conditions for old and new technologies, eradicating hunger, improving food security and health, and achieving energy security remain overarching priorities for developing countries, particularly those countries in special situations.

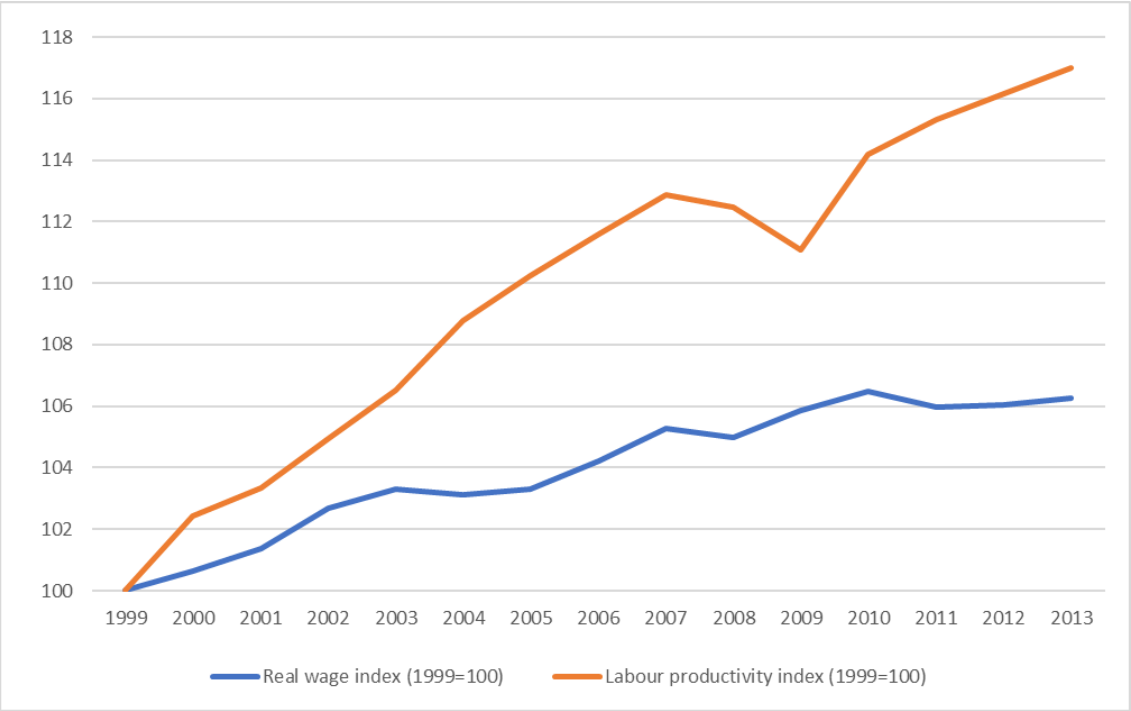
Governments in developed countries will need to make complementary investments in skills, education and social protection so as to ensure that gains in efficiency and productivity are balanced by equity considerations and ethical standards, to ensure basic minimum income, individual choice, transparency and accountability.

Targeted adoption of frontier technologies may, on the other hand, enable developing countries to enhance economic efficiency, environmental sustainability, and delivery of educational and health services and thus improve inclusion and equity. Investing in physical infrastructures — computers, broadband networks and markets — and education, and strengthening R&D capacities for replication, improvisation and diffusion of relevant technologies, as well as developing institutional and regulatory frameworks to maximize the sustainable development impact of frontier technologies, while removing constraints on the adoption of existing technologies, will be critical for leapfrogging to sustainable development.

Creating decent jobs and reining in inequality

The rapid advances in AI and robotics represent a breakthrough for advancing sustainable development in countries at the technology frontier. They offer opportunities to expand automation to encompass new areas of work, which has an immense potential for generating productivity gains, higher wages and decent work. Automation will eliminate tasks and possibly entire occupations; at the same time, however, productivity gains may have spillover effects on other sectors, with an increase in demand for non-automatable tasks that require common sense, adaptability, empathy and creativity. The pace and sequence of automation will determine the type and number of jobs in the future economy. On the other hand, there is a growing divergence between improvements in productivity and real wages (see figure III), which raises concerns that automation-led productivity enhancements may further depress future wage growth. Many new jobs, especially in AI, will require higher levels of knowledge and skills but educational systems may lack the ability to foresee and respond to the growing demand for new skills.

Figure III
Average wages and labour productivity in selected G20 countries, 1999–2013



Source: International Labour Organization, *Global Wage Report 2014/15: Wages and Income Inequality* (Geneva, International Labour Office, 2015).

Note: Data refer to Australia, Canada, France, Germany, Italy, Japan, the Republic of Korea, the United Kingdom of Great Britain and Northern Ireland and the United States of America. Real wage growth is calculated as a weighted average of year-on-year growth in real average monthly wages in the advanced G20 economies (for a description of the methodology, see ILO *Global Wage Report 2014/15*, appendix I). Index is based on 1999 because of data availability.

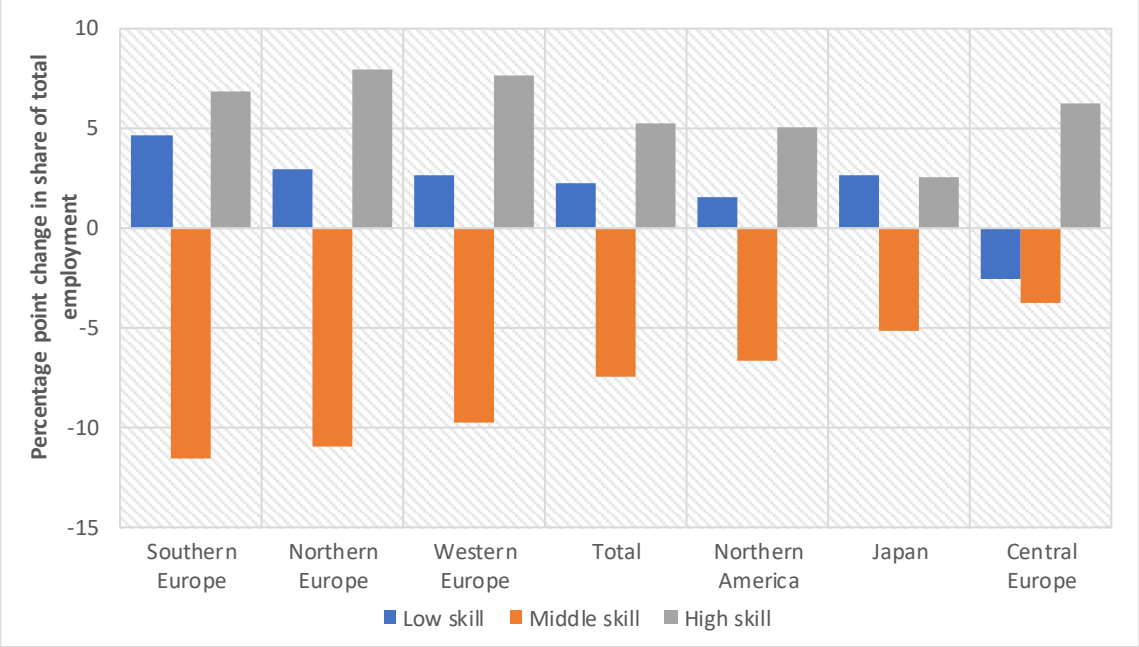
Automation-induced adjustments in labour markets — reducing labour demand in one sector and increasing demand in others — may require years, if not decades, while often increasing unemployment and inequality in the short to medium run. Job losses to automation in medium-skill sectors may not be adequately offset by job gains in relatively low-paying, low-skill and low-productivity sectors. While the net effect of automation on total employment may be nil, the effects on the average wage may still be negative, contributing to a reduction in the share of labour income (i.e., the share of gross domestic product (GDP) going to labour compensation) and rising income inequality. The computerization and robotization of the economy, which will expand with advances in AI, machine learning and robotics, are clearly an important explanation for polarization of the labour markets over the past decades in countries that are members of the Organization for Economic Cooperation and Development (OECD) (see figure IV). Recent work by the World Bank (2016)[7] indicates that labour markets have also become more polarized in many developing countries since the mid-1990s.

The skill-biased technological change and polarization of labour markets have significantly affected wage inequality. In the majority of developed countries, wage inequality is higher today than 40 years ago, with the bulk of the increase having occurred in the 1980s and 1990s. A new wave of automation can worsen wage

[7] See World Bank, *World Development Report 2016: Digital Dividends* (Washington, D.C., 2016). doi:10.1596/978-1-4648-0671-1.

inequalities through changing distribution between capital and labour income. Labour income share has been declining consistently across advanced economies since the 1990s. In some emerging economies, notably in Asia and Northern Africa, the decline in labour income share is even more pronounced than in the OECD countries.

Figure IV
Skill polarization in labour markets of OECD countries, 1995–2015



Source: UN/DESA, based on data from *OECD Employment Outlook 2017* (Paris, 2017).

Countries that take advantage of automation opportunities will need to make concerted efforts to protect workers who are adversely affected and to reverse the trends of rising wage and income inequality. This is a must not only for achieving inclusive growth and sustainable development, but for ensuring peace and stability as well. Investments in new skills development and training, as well as in stronger labour-market institutions and better social safety nets, will be critical. Redistributive policies, i.e., expanding social protection and providing a basic minimum income, will reduce the pains of adjustments within the labour market and stabilize, if not reduce, income inequality.

Creating enabling conditions

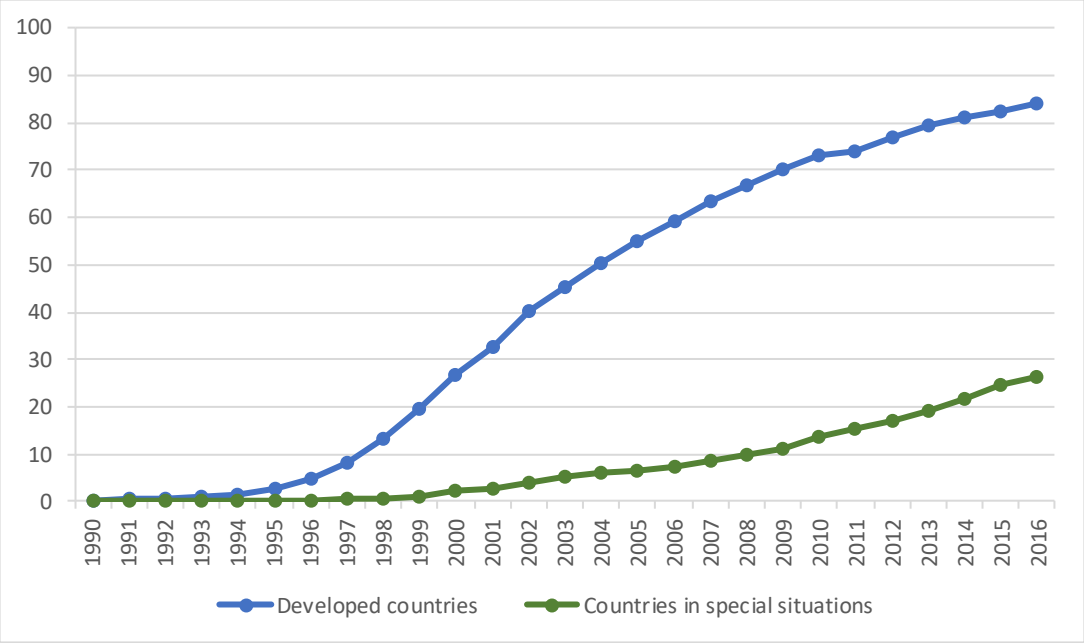
While the promise of frontier technologies is alluring, many developing countries have yet to exploit the benefits of existing technologies. An estimated 1.1 billion people in those countries still have no access to electricity and a further 2.5 billion are defined as “under-electrified”, that is, they live in areas where connections are weak and power outages are common.[8] Subsistence farmers in these economies still rely exclusively on manual labour and animal power. Access to safe drinking water and improved sanitation remain lacking for nearly 30 per cent of the population in least developed countries.

[8] See “A brightening continent: solar is giving hundreds of millions of Africans access to electricity for the first time” (special report), *Economist*, 15 January 2015. Available at http://www.economist.com/news/special-report/21639018-solar-giving-hundreds-millions-africans-access-electricity-first.

A population group deprived of electricity, clean water and improved sanitation cannot possibly acquire a minimum level of the education or skills needed to be able to use frontier technologies, let alone innovate or improvise those technologies to meet local requirements. The Internet has enabled people and businesses in unconnected areas to join the global information society and has become an important tool for learning and development of human capital. Yet, more than half of the world's population, the majority of them living in least developed countries, are still not using the Internet. There is considerable disparity in Internet use between developed and developing countries in special situations (figure V), as well as significant within-country gaps in Internet access between men and women, urban and rural areas, and young and old. Indeed, low levels of Internet access in many developing counties will undermine the adoption of data-driven frontier technologies.

Figure V

Percentage of the population using the Internet, developed countries and countries in special situations, 1990–2016



Source: Elaboration of UN/DESA, based on World Development Indicators Online.

The development, replication, improvisation and diffusion of new technologies will require improvement of the knowledge and skill base of populations, and appropriate policy measures and incentives, as well as an enabling institutional framework. Many developing countries will need to enhance their efforts to create the enabling conditions that will accelerate development of human capital, which will be critical for their taking advantage of the advances in frontier technology. Those countries will also need to eliminate or ease constraints on accessing existing technologies, including electricity, water and sanitation, which are minimum requirements for a decent and productive livelihood.

Many developing countries will also need to develop appropriate regulatory and institutional frameworks for managing the deployment and application of frontier technologies. Decentralization of capital, as evidenced among crowd-based service platforms, exposes service providers to new kinds of risks and uncertainty. Service providers lack job protection, income security and benefits, while platform owners extract most of the surpluses. Often, consumer protection is also weak, creating room

for price discrimination, fraud and exploitation. Ethical guidelines and legal frameworks are also needed to ensure that questionable products and services are not beta-tested on unsuspecting consumers in developing countries.

Developing countries will also need to strengthen their innovation systems to improve policy coordination, facilitate information exchange and reduce duplication and waste. Given widespread information asymmetry, firms in those countries may unknowingly duplicate earlier efforts of other firms in developing a technology. They may also waste scarce resources on developing a new technology from scratch while ignoring the potential for low-cost improvisation of existing technologies. A well-functioning national innovation system should also facilitate exchange of information and knowledge, especially knowledge related to patents and their costs, to enable firms to acquire new technologies at reasonable costs.

Sustainable development of developing countries will require them to access both existing and emerging technologies, without facing significant constraints. An intellectual property rights regime, supporting key sustainable development goals of securing food, health and environmental outcomes, will remain critical for reducing the technological divide and improving access. International consensus on treating certain technologies as global public goods, based on the principles of shared and differentiated responsibilities among all countries, will ensure win-win sustainable development for all.

Eradicating hunger and improving food security and health

Developing countries, particularly many countries in special situations, face a chronic shortfall in food production. Draughts, flooding and pest attacks often destroy yields and exacerbate hunger and malnutrition. Food shortages often result in low immunity and undermine public health. Breakthroughs in biotechnology, however, can significantly improve food security and health care. Genetic biofortification of food crops can help to reduce micronutrient deficiencies and mitigate malnutrition through nutritional enhancement of foods. Analysis of large population data, and use of AI, to identify key trends and challenges can complement breakthroughs in biotechnology, enabling their application to targeted population groups facing micronutrient deficiencies. And drones can facilitate delivery of seeds and biofortified crops to locations otherwise inaccessible because of underdeveloped road systems.

Biotechnology can also facilitate a more accurate diagnosis which can in turn facilitate prompt treatment, limit the spread of disease and prevent the waste of resources. For example, some recombinant vaccines for malaria and hepatitis available at a fraction of the cost of standard imported medicines have been tested in some developing countries with promising results. Identification of plant substances and agents with healing properties for producing plant-derived pharmaceuticals (PDPs) presents immense potential for low-cost drugs and vaccines and facilitating the development of a domestic pharmaceutical industry.[9] Prospects for plant-derived pharmaceuticals are being undermined, however, by the absence of markets as well as by biosafety and bioethics-related concerns and a lack of public awareness. Introducing biosafety policies for first-generation transgenic plants, which belong to the category of genetically modified organisms, and establishing institutional frameworks can advance production of PDPs to support sustainable health outcomes. Developing countries may also take advantage of advances in nanotechnology,

[9] See Ameenah Gurib-Fakim and Jacobus Nicolaas Eloff, eds., *Chemistry for Sustainable Development in Africa* (Berlin, Springer-Verlag, 2013).

precision technologies and AI to make plant-derived pharmaceuticals commercially viable for their large populations.

Economic efficiency and protecting the environment

A number of countries are taking concrete steps to mitigate CO_2 emissions and enhance environmental sustainability in line with their commitments under the Paris Agreement, adopted under the United Nations Framework Convention on Climate Change,[10] and the 2030 Agenda. Large emerging countries, including Brazil, China and India, are also making similar efforts to reduce CO_2 emissions. Many of these countries are prioritizing the development and deployment of electric vehicles[11] (EVs) to meet emission reduction targets. EVs are recognized as an important innovation for achieving the global CO_2 reduction targets of the Paris Agreement, mainly because the levels of their tailpipe CO_2 emissions are extremely low. EVs can offer economic efficiency in terms of low variable costs for fuel, while enhancing environmental sustainability.

Many countries provide direct and indirect incentives to encourage the use of EVs. Financial incentives include zero or lower taxes, while indirect incentives include exemptions from restricted access to urban areas, dedicated parking spaces and the privilege of using bus lanes and high-occupancy vehicle lanes during rush hours. Many Governments also provide direct support for EV-related R&D. Use of EVs does not, however, necessarily lead to a reduction in CO_2 and other greenhouse gas emissions, which depends on the total life-cycle emissions of a vehicle, including its manufacture, battery production, operation, maintenance, discharge and lifetime energy consumption. The reduction of emissions is maximized when an EV makes exclusive use of renewable energy (which currently accounts for only 20 per cent of total electricity generation worldwide). The use of 3D printing technology to manufacture electric vehicles, and of AI for their navigation, may contribute to further reducing their total life-cycle emissions and enhancing their economic efficiency.

Economy-wide impacts also depend on consumer preferences for EVs as the major mode of transportation. EVs are not yet viable options for many users in countries with a vast expanse of rural areas because of the scarcity of electric charging stations and the fact that EVs can run only relatively short distances with a single charge. The high price of an EV means that only affluent commuters can afford them. Consequently, financial incentives for EVs end up being subsidies for the rich, which raises equity concerns. Complementary investments for expanding battery capacities, reducing EV prices, building charging stations and expanding renewable sources will enhance the sustainable development potential of EVs.

Achieving energy security

Developing countries, especially countries in special situations, must face the daunting challenges of ensuring energy security and expanding access to affordable electricity. This adversely impacts educational attainment, skills development and accumulation of human capital. The share of renewable energy is particularly low in many developing countries. RETs have the potential to generate an output over 3,000 times greater than that needed to meet current global energy needs.[12] They can offer win-win outcomes, particularly in energy-deficit developing countries, by improving

[10] United Nations, *Treaty Series*, No. 54113 (vol. still to be determined).

[11] The EVs examined in the present section are powered through batteries or solar panels or through the conversion by an electric generator of fuel (mainly hydrogen) to electricity.

[12] Omar Ellabban, Haitham Abu-Rub and Frede Blaabjerg, "Renewable energy resources: current status, future prospects and their enabling technology", *Renewable and Sustainable Energy Reviews*, vol. 39 (C) (November 2014), pp.748–764.

efficiency, creating jobs, promoting social inclusion and equity, and reducing greenhouse gas emissions and enhancing environmental sustainability. In remote off-grid locations, stand-alone household-size RETs, such as solar photovoltaic and wind turbines, can be deployed closer to the source of demand, reducing distribution and transmission costs as well as energy and capacity losses.

The high cost of RETs remain a barrier, however, particularly in developing countries that lack the fiscal space necessary to provide financial incentives for development, diffusion and adoption of those technologies. In developed countries, households are typically more well informed regarding the advantages and disadvantages of RETs, which makes it easier for them to switch to renewables. Often, moreover, there is also greater collective awareness of environmental concerns. In contrast, poor households in many developing countries frequently lack necessary RETs-related information and awareness. For example, they may be discouraged from switching to RETs because of a one-time installation cost which is high relative to conventional sources, while completely ignoring longer-term cost advantages. Further, they may not trust RETs as a dependable source of energy, especially during the initial stages of their deployment in a community. There is a clear need, then, for building trust in a new technology. Community-level investments in disseminating information on the cost efficiency of RETs may facilitate their widespread adoption. There is also a clear need in many developing countries for provision of financial incentives through which to promote RETs as an important means of achieving energy security and sustainable development.

Ensuring social cohesion, peace and stability

Against the backdrop of persistent environmental challenges, rising income inequality and a growing sense of economic insecurity, countries across the world need to make concerted efforts to ensure stability, peace and harmony in societies.

In this regard, social media, for example, have greatly transformed social interactions, increasing sociability and civic engagement and the frequency — if not always the depth — of interactions. Intense use of social media, on the other hand, has arguably increased isolation, alienation and withdrawal from society. The algorithms that drive social media determine the selection and sequencing of the information displayed to users, which can profoundly impact their perceptions, beliefs, attitudes and actions. Those algorithms have also enabled the rapid spread of disinformation, which polarizes users and undermines civic discourse.

Algorithms increasingly inform and facilitate decision-making in both the private and public sectors, for example, in hiring and providing loans and social services, including child protection services, as well as in criminal justice systems. While algorithms can enable firms and public institutions to make more informed decisions, they can also reinforce existing biases and prejudices, and exacerbate discrimination and social exclusion. Frequently described as tools of objectivity, algorithms in fact generally encode human prejudice and biases within automatic systems, Often, the negative effects of this impact minorities and vulnerable groups disproportionately. While an individual can be held accountable for a decision, there is no mechanism for ensuring the transparency and accountability of opaque “black box” algorithmic decision-making. There is therefore a need for clear and agreed guidelines to ensure accountability and transparent use of algorithmic decision-making processes.

Data security and privacy are critical factors for ensuring trust and accountability in cyberspace. Security breaches compromise the private information of users, which can be valuable, marketable assets for a range of third parties. In the data economy, excessive concentration of personal data can confer undue market

power on a few large firms (e.g., credit rating agencies, social media platforms and online retailers) and render users and consumers vulnerable to various forms of manipulation, including price discrimination and discrimination related to access to relevant information or services. There is a clear need to define data ownership so as to protect property and privacy rights of individuals and ensure responsible use of data. This will also ensure accountability and integrity of social media, crowd-based platforms and online trade and promote trust and stability in the digital world.

III. National innovation systems for sustainable development

Technological progress has been uneven across countries. Innovation and technological breakthroughs are highly concentrated among a small set of developed countries, along with a few large developing countries. A majority of developing countries have yet to play a significant role in innovation, underlining a persistent and widening technological divide between them and developed countries. A technological divide also persists within countries. There is a growing technology gap between firms that are at the national technological frontier and those that are not. Even as technologies make their way into new countries at a faster rate, data show that the speed of diffusion of technologies inside a country has decreased. In the key field of AI, patent generation is also highly concentrated in a few firms, even in the most technologically advanced countries.

National innovation systems

The ability of countries and firms to reach the technological frontier — to catch up and keep up — requires a well-functioning national innovation system (NIS). However, there is no unique model of a successful national system applicable to all contexts. Both market and State-led innovation systems exist, reflecting broad divergences in strategies among countries that leaped to the technological frontier. An innovation system, whether market- or State-led, involves a range of stakeholders: the private sector, universities, research institutions, think tanks, advocacy and pressure groups, and government agencies and enterprises. Interactions and linkages among these stakeholders help to identify key challenges, including the research agenda, funding requirements, innovation and patent rights, as well as the translation of innovations into viable and marketable technologies. In market-led systems, efficiency considerations and profit motives determine innovation choices, while State-led systems tend to prioritize innovation that promotes growth, social or public health outcomes.

The linkages within a national innovation system are complex and the success of a country's innovation efforts relies on how networks of actors interact with each other in generating and diffusing innovation. Efficacy of a national system depends on market structure and competition. Competitive markets incentivize firms to continue to innovate and gain an edge over other competitors. On the other hand, too much competition can lower revenue and profits, which reduces firms' space for investment in R&D activities.

In addition to market competition, regulations play an important role in ensuring a level playing field for technology developers. Intellectual property (IP) regulation often determines the trajectory of national innovation endeavours. Too little IP protection, without alternative mechanisms for compensating innovators, can risk discouraging innovation. On the other hand, overly stringent IP protection also hampers innovation, as it constrains knowledge flow and impedes future innovations. Regulation is also central in ensuring that technological advances improve social welfare.

A successful national innovation system also requires complementary infrastructure, including legal and business services, telecommunications and transportation. The emergence of so-called open science, where research data, laboratory notes and other research processes are freely available, could play a significant role in strengthening national innovation systems. Open science has facilitated the involvement of non-traditional actors, including smaller research groups and independent researchers, in complex innovation activities.

Fostering of innovation by Governments

While the private sector leads, Governments can still play a fundamental role not only in addressing market failures but also in shaping future innovations and supporting the development of emerging technologies at initial stages. Public investments in quality education and skill development are key to fostering innovation. Government institutions, by ensuring healthy market competition and appropriate regulatory frameworks, shape successful innovation efforts. Differences in terms of human capital, access to finance and qualities of institutions and infrastructures contribute to existing technological divides both between and within countries. Governments can play an important role in bridging the divide by guiding and incentivizing innovation for communities and societies experiencing a lag in technological progress. The public sector R&D budget, through improving access to basic research in science and technology, may help to create an even playing field for all firms. Governments can also facilitate technology transfer among firms and sectors through changes in IPR regimes.

Governments influence innovation by setting appropriate standards, since promoting certain standards can help to kick-start the penetration of new technologies into the marketplace. They can establish a proper IPR regime to ensure: that firms are sufficiently incentivized to innovate and, at the same time, that technical information contained in patent documents is publicly accessible, so that innovation can exert positive spillover effects. Governments can directly fund the development of new products that have enormous potential for improving social welfare but lack commercial viability, especially in periods of economic slowdown when firms are unable to take risks with such products. Well-designed tax incentives can also encourage innovation, including R&D-related tax incentives for small and new firms.

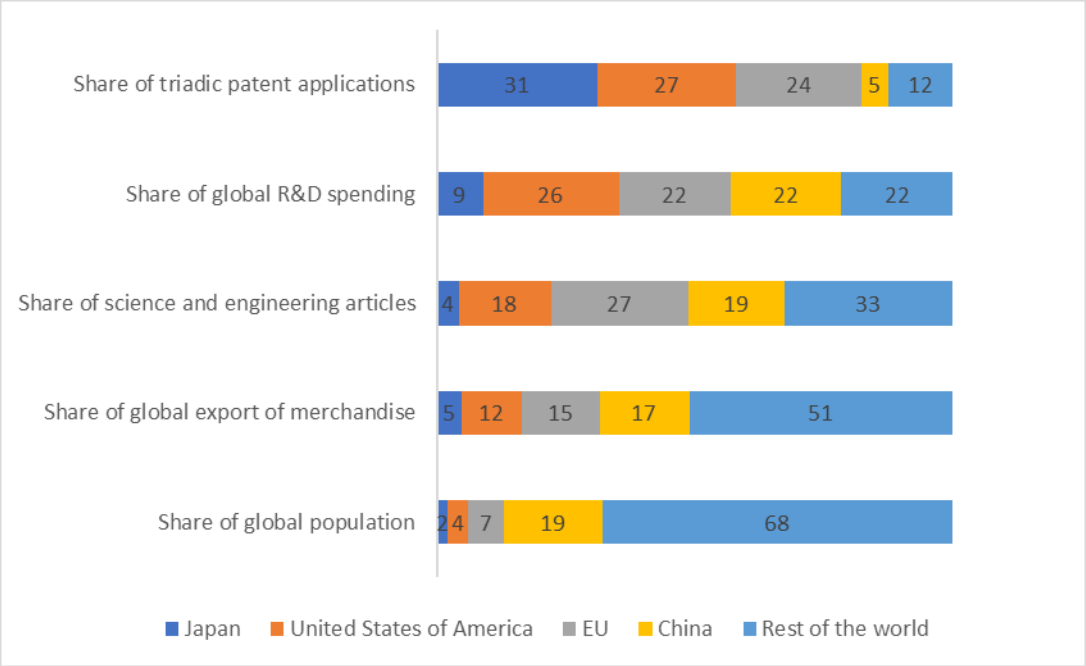
Governments need to play an active role in technology diffusion. Their concerted efforts are especially important considering that there is an imminent risk that technology information flows and complementary network effects could be largely confined to clusters of countries or firms with high technological capacity, as a result of which other countries and firms would be excluded from benefiting from the type of technology dynamism that could help them reach the technology frontier. Governments can improve access to technology-related information and address firms' capacity constraints to help them cope with the uncertainties associated with the adoption of technology and their financial constraints. Tax policies can influence firms' and households' technology choices. At the international level, technology transfers are largely conducted through international trade and foreign direct investment (FDI), under the influence of IPR regimes. Governments may play an important role in technology diffusion, through skilful negotiation of complex international trade and investment agreements.

The great technological divide

A few large firms, leading advances in emerging technologies, are concentrated in a limited number of countries. The technological divide between developed countries and the rest of the world economy, when measured by the numbers of patent applications or R&D expenditures, is wide and growing. China, the European Union,

Japan and the United States of America, representing 32 per cent of the world's population during 2013–2015, collectively account for a far larger global share in scientific publications (69 per cent), research and development spending (83 per cent) and triadic patent applications (86 per cent) (see figure VI). The technological divide is even more acute in the realm of frontier technologies. Fujii and Managi (2017)[13] found that the United States alone accounted for an overwhelming 75 per cent of global AI patents granted during 2016–2017. Within a country, similar trends have been recorded with respect to the technological divide among firms, with a few large firms being shown as dominating production of frontier technologies. AI patents data, for example, reveal that patent generation is universally dominated by only a few large firms.

Figure VI
Share of global for various activities, selected countries and the European Union, 2013–2015



Source: Elaboration of UN/DESA (2017), based on data from OECD, the United Nations Educational, Scientific and Cultural Organization (UNESCO), the National Science Foundation (United States of America), the World Trade Organization and the Population Division of the United Nations Secretariat.

Note: Triadic patents are a set of patents filed at the three major patent offices (the European Patent Office, the Japan Patent Office and the United States Patent and Trademark Office) to protect the same invention.

A handful of developed and developing countries play a dominant role in rolling out frontier technologies. These countries are at the edge of the technology frontier. While there are divergences among these countries in terms of per capita income, geography and political structure, they all tend to spend a relatively high share of their national income on R&D. Per capita GDP, the commonly used measure of a country's development status, is not necessarily the predictor of how much a country spends on R&D. Countries such as Czechia, Estonia, Israel and Slovenia spend a

[13] Hidemichi Fujii and Shunsuke Managi, "Trends and priority shifts in artificial intelligence technology invention: a global patent analysis", Rieti Discussion Paper 17-E-066 (Tokyo, Research Institute of Economy, Trade and Industry, May 2017).

significantly higher proportion of their national income on R&D than do Greece, Italy and Spain, which have higher per capita incomes. A high level of R&D expenditures, along with complementary investments in education and skills development, have enabled many countries to move closer to the technology frontier, assume leadership in certain technologies and bridge the technological divide.

Addressing technological divides within and across countries will also require a global commitment to shared and differentiated responsibilities for the generation, diffusion and adoption of frontier technologies, especially technologies most critical for sustainable development. Countries leading in the innovation of frontier technologies have a special responsibility to manage their diffusion and adoption so as to ensure a balance among efficiency, equity and ethical considerations.

IV. Harnessing international cooperation for sustainable generation and diffusion of technologies

Rapid advances in frontier technologies have rendered many traditional institutions, policies and regulations inadequate and ineffective for addressing the opportunities and challenges presented to societies by emerging technologies. Unforeseen and unanticipated policy challenges arise from the uneven pace of technological diffusion, technologies' economic impacts within and across countries, the way in which new technologies transcend sectoral, jurisdictional and regulatory boundaries, and their impact on perception, behaviour and biases. While the potential benefits of frontier technologies are immense, the risks and uncertainties associated with their adoption and use are also significant. Isolated national-level efforts will be insufficient to meet the challenges of maximizing the potential benefits of frontier technologies, while minimizing their unintended adverse consequences. There is an unequivocal need for stronger and more effective international cooperation, including provision of adaptability and flexibility, so as to ensure that frontier technologies deliver sustainable development outcomes.

While national policies will remain central to managing advances in emerging technologies, strengthened international cooperation will be needed to narrow technological divides across countries; address the concentration of market power; improve international tax cooperation; and erect the ethical boundaries and standards needed to guide advances in frontier technologies, particularly in AI, genetics and biotechnology.

Bridging the technological divide

Narrowing the technological divide requires addressing a set of supply- and demand-side institutional challenges. In leveraging technology to improve social welfare, policy interventions typically focus on supply-side constraints on technology generation and transfer. There is a growing recognition that easing access to technology does not necessarily generate their widespread adoption. New technologies, e.g., an improved sanitation system or a renewable energy technology, can remain unviable in the absence of demand for such technologies, whether for economic, political, cultural or religious reasons, within the communities themselves. There needs to be concerted efforts at national and international levels to generate greater awareness regarding frontier technologies and their potential impact on sustainable development.

Formal and informal institutional constraints often hinder adoption of new welfare-improving technologies. Institutional efforts should facilitate the spread of technology information, raise awareness, improve access to finance, strengthen capacities, and introduce mechanisms that enable firms and households to hedge

against technology-related uncertainty and risks. Institutional efforts are also required to ensure privacy, security and accountability, which is crucial for fostering public trust in technology. Efforts to reduce technological divides will require incentives and additional financing, which will make international cooperation even more necessary.

Legal and institutional flexibilities are necessary preconditions for facilitation of technology transfer, since the evidence has shown that the rigidity of the global IPR regime has made technology transfers increasingly difficult. Addressing such rigidities requires a multi-pronged approach, including flexibilities in determining national patentability standards, maintaining or even expanding patent exemptions for developing countries, creating conditions that make compulsory licensing more feasible and effective, and ensuring inclusive access to technology data.

Harmonizing national and international technology standards is also crucial for bridging the technology divide. A unified national standards strategy can help prevent the duplication of efforts and the adoption of conflicting standards. Increasing government participation in market-led technology standard-setting processes can ensure that the resulting technology standards will facilitate their diffusion and adoption, especially if they are critical for sustainable development. Governments should work together to establish and ensure consistent interpretation of international principles on standard-setting.

Governments also need to secure and maintain sufficient policy space for management of advances in frontier technologies in accordance with their domestic development objectives. There is a clear need for the international community to revisit current international agreements, including the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS Agreement),[14] and to address issues that constrain the policy space of developing countries. In addition, an international mechanism is urgently needed to identify a set of frontier technologies critical for sustainable development. A new international consensus should declare these critical technologies to be global public goods and make them available to societies and communities, which would reflect a commitment to shared and differentiated responsibilities among all stakeholders.

Addressing the concentration of market share in frontier technologies

There has been a broad global trend towards greater market concentration across industries, especially in many frontier technologies. Dominant technology firms are increasingly exploiting network effects, economies of scale, economies of scope, and their oversized influence on regulatory processes. The advantages allow many large firms to remain dominant without necessarily being more innovative, which prompts calls for the strengthening of competition policies. Assessing anti-competitive behaviour also becomes more complicated, as algorithms can enable individualized pricing and thereby make it difficult for competition authorities to accurately assess the prices charged by firms.

The current patent systems may further exacerbate anticompetitive behaviour. Significant increases in the number and complexity of patent applications have generated backlogs and longer patent pendency periods, which results in greater uncertainty regarding what inventions are or will be protected by patent rights. This creates opportunities for firms to adopt anti-competitive strategies. Further, the consistent rise in patent litigation costs is often a disadvantage to smaller firms whose

[14] See *Legal Instruments Embodying the Results of the Uruguay Round of Multilateral Trade Negotiations, done at Marrakesh on 15 April 1994* (GATT secretariat publication, Sales No. GATT/1994-7).

limited financial resources prevent them from either pursuing or defending patent infringement cases.

Growing market power and diminished competition in frontier technology sectors demand stronger international cooperation on competition policies. Uneven levels of regulatory stringency across countries — a function of insufficient international cooperation — hurt consumer welfare. Insufficient international cooperation also hampers the ability of national competition authorities to enforce their national laws and imposes an extra administrative burden on those authorities and related organizations during their investigation of anti-competitive behaviours. Given the importance of international cooperation, national competition authorities would need to develop more effective mechanisms for exchange of information on anti-competitive behaviour and for effective enforcement of competition-related laws.

Strengthening international tax cooperation

Technological advances and digitalization have changed the way in which firms carry out their global activities. Digitalization allows firms to be economically active in a country or region with little or no substantive physical presence, which limits Governments' ability to tax the income derived from those activities. Digitalization also allows large firms to centralize their functions in what are often very low tax or no-tax jurisdictions, raising concerns related to base erosion and profit shifting.

Governments in both developed and developing countries face growing challenges with respect to (a) collection of adequate revenues to finance sustainable development-related expenditure — on, for example, social protection systems and floors and (b) fulfilment of the redistributive function of the tax system. Developing countries especially may be hit hard by the complexities and revenue risks arising through digitalization owing to constraints on human resources and limited access to technological resources. Strengthening national capacities to tax digital transactions of multinational enterprises, particularly in developing countries, could enable many of those countries to fund sustainable development priorities as well as national initiatives to facilitate adoption and diffusion of relevant technologies.

There is a pressing need for strengthened international cooperation to enable more effective taxation of profits, and close loopholes which allow large multinational enterprises, including technology firms, to reduce their tax liabilities. An international consensus is needed to define new taxing rules capable of accurately targeting and taxing profits derived from digital activities. As digitalization expands, international tax systems should be reoriented towards taxing profits at the locations where activity is conducted and value is added. This principle was agreed by Heads of State and Government and High Representatives in the Addis Ababa Action Agenda of the Third International Conference on Financing for Development.[15] Views differ on which activities create value and how much, where they take place and how the derived profits should be distributed between countries in such a way as to reflect value creation while preventing burdensome double taxation. Taxation of search engines and social media platforms, which provide free services to users across borders but also gather data that enable them to sell targeted advertisements and earn revenues without physical presence, poses new challenges to tax authorities.

The Committee of Experts on International Cooperation in Tax Matters analyses opportunities in the digitalized economy for improving the revenue administration and combating tax avoidance and evasion, to enable the generation of new and additional resources for financing sustainable development.

[15] General Assembly resolution 69/313, annex.

Setting appropriate standards and ethical boundaries

Managing advances in new technologies is an absolute necessity for ensuring equity and social justice and achieving sustainable development. Increasing transparency and accountability in R&D of frontier technologies, such as gene editing, cloning, biotechnology and AI, will remain critically important in aligning technological advances with universal values, ethics and morality.

Societies need to consider ethics, values and social ramifications of frontier technologies proactively at all stages of their development, instead of adopting a laissez-faire approach and addressing challenges ex post facto. Governments, businesses, academia and civil society in developed countries should collaborate among themselves and with stakeholders in developing countries to promote ethical standards for guiding research and innovation. While national efforts will set the stage, greater international cooperation is a must for developing global ethical standards for frontier technologies, taking into account the differences in contexts across countries.

Forging global collective action: the role of the United Nations

While many frontier technologies present immense opportunities for fostering sustainable development, they also pose considerable risks. A global dialogue, involving all stakeholders, is needed to identify those risks and opportunities. The United Nations can serve as an impartial facilitator among Governments, the private sector and civil society organizations with regard to conducting an objective assessment of the impact of emerging technologies on sustainable development outcomes, including the impact on employment, wages and income distribution. A multidimensional multi-stakeholder assessment of opportunities and risks will enable Member States to identify appropriate policies for managing frontier technologies.

In this regard, the Science, Technology and Innovation Forum, a multi-stakeholder platform which is forging a common understanding among scientists, policymakers and the private sector and promoting tangible development results, plays an increasingly important role. The Commission on Science and Technology for Development, the Technology Bank for the Least Developed Countries, and the Artificial Intelligence for Good Global Summits organized by the International Telecommunication Union are other important United Nations initiatives for facilitating understanding of relevant technologies and their sustainable development impact, which bridge some of the dimensions of the technology divide.

The United Nations can play a vital role in identifying and designating certain critical frontier technologies as global public goods for sustainable development. Renewable energy technologies that promote environmental sustainability, vaccines that save lives, biotechnologies that boost food production and eliminate hunger, can all be deemed global public goods which protect our common future. In this regard, the United Nations will be required to forge a global commitment based on shared and differentiated responsibilities among all actors.

The United Nations can also leverage its convening power to bring Member States and all relevant stakeholders together to adopt a global consensus on legal and ethical standards for guiding R&D of frontier technologies. Technological advances must include a respect for such universally held ethical standards. The United Nations — given its universal membership and unwavering commitment to human values — is uniquely positioned to facilitate a dialogue among all stakeholders and the development of a global ethical compact for managing the advances in frontier technologies.