Industrial Development Report 2020

Industrializing in the digital age
Overview

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INDUSTRIAL DEVELOPMENT ORGANIZATION

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Foreword

The emergence and diffusion of advanced digital production (ADP) technologies of the fourth industrial revolution are radically altering manufacturing production, increasingly blurring the boundaries between physical and digital production systems. Advances in robotics, artificial intelligence, additive manufacturing and data analytics generate significant opportunities to accelerate innovation and increase the value-added content of production in manufacturing industries.

This 2020 Industrial Development Report contributes to the debate on the fourth industrial revolution by presenting fresh analytical and empirical evidence on the future of industrialization in the context of the present technological paradigm shift.

One frequent claim is that robots will replace factory workers, such that industrialization will not create the same number of job opportunities as in the past. Another is that advanced countries will back-shore previously outsourced production. A third is that the minimum threshold of skills and capabilities to remain competitive in manufacturing will be so high that it will exclude most countries from the next phase of manufacturing production. This report empirically examines the validity of these challenges.

A key finding of this publication is that industrialization continues to be the main avenue for successful development. Industrialization enables countries to build and strengthen the skills and capabilities to compete and succeed within the new technological paradigm. The analysis shows that ADP technologies applied to manufacturing production offer huge potential to advance economic growth and human well-being and to safeguard the environment, contributing to the 2030 Agenda for Sustainable Development. This concerns, in particular, Sustainable Development Goal 9—Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation—which is central to UNIDO's mandate. These technologies can increase the efficiency and productivity of industrial production processes, and there is evidence that it can also help create new industries.

This publication also shows that, although a large number of jobs will be vulnerable to automation as new technologies diffuse across countries and industries, it is also likely to create new industries and new job opportunities in more skilled and knowledge-based sectors. The evidence in this report suggest that, once indirect effects along the value chain are considered, the increase in the stock of robots used in manufacturing at the global level is actually creating employment, not destroying it. Evidence on back-shoring from emerging to industrialized economies due to the adoption of new technologies indicates that this phenomenon is not widespread. Findings show that back-shoring is counterbalanced by offshore production in developing countries, which creates opportunities for jobs, backward and forward value chain linkages.

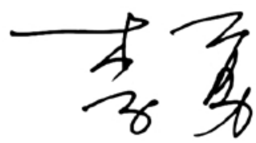
The impact of ADP technologies on developing countries will ultimately depend on their policy responses. There is no "one-size-fits-all" policy strategy to make the new technologies work for inclusive and sustainable industrial development. Our 2020 report provides some strategic policy directions as the fourth industrial revolution deepens in the coming years. Three areas deserve particular attention: (i) developing framework conditions, in particular digital infrastructure, to embrace the new technologies; (ii) fostering demand and leveraging on ongoing initiatives using ADP technologies; and (iii) strengthening required skills and research capabilities. The report provides several examples of specific policies currently implemented in different countries to address each of these dimensions.

A striking finding emerging from the report is the large number of countries that have yet to enter into the era of ongoing technological breakthroughs. Large parts of the world, mostly in least developed countries and other low-income countries, are still far from utilizing ADP technologies on a significant level. Firm-level data collected for this report in five developing countries reinforce this understanding by showing that the manufacturing sector in these countries is characterized by “technology islands”, where few (if any) digital leaders coexist with a large majority of firms using outdated technologies. Up to 70 percent of the manufacturing sector in “lagging economies” are still using analog technologies in its manufacturing production.

The lack of diffusion of potentially useful technologies strengthens the call for the further enhancement of the global partnership for sustainable development. Efforts to mobilize and share knowledge, expertise, technology and financial resources to secure the aim of 2030 Agenda for Sustainable Development to leave no one behind must be increased. Low-income countries require appropriate digital infrastructure and skills to take advantage of the fourth industrial revolution and to avoid the risk of lagging further behind. This report shows that there are merits for low-income countries to engage in manufacturing production, to strengthen industrial capabilities and learn how these technologies can be used productively. Sustained, inclusive and sustainable economic growth is essential for prosperity.

I am pleased that this report brings an original dimension to the analysis of new technologies and the fourth industrial revolution, and reaffirms the role of industrialization as a driver of development. Industrial development that is inclusive and sustainable will help build dynamic, sustainable, innovative and people-centred economies—this we must strive for, as the international community progresses towards the achievement of the 2030 Agenda for Sustainable Development.

I thank the UNIDO staff members and international experts who worked on this report, and I look forward to it serving as a reference document in the international development debate on the fourth industrial revolution.



LI Yong
Director General, UNIDO

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Abbreviations

1IR	First industrial revolution
2IR	Second industrial revolution
3IR	Third industrial revolution
4IR	Fourth industrial revolution
ADP	Advanced digital production
BRICS	Brazil, Russian Federation, India, China and South Africa
CAD	Computer-aided design
CAM	Computer-aided manufacturing
CIM	Computer-integrated manufacturing
CNC	Computerized numerical control
CIP	Competitive industrial performance
CPS	Cyber-physical system
DPT	Digital production technologies
GDP	Gross domestic product
GVC	Global value chain
ICIO	Inter-country input-output
ICT	Information and communications technology
IDR	Industrial Development Report
IoT	Internet of Things
ISID	Inclusive and sustainable industrial development
KIBS	Knowledge-intensive business services
LDC	Least developed countries
M2M	Machine-to-machine
MVA	Manufacturing value added
R&D	Research and development
RFID	Radio-frequency identification
SDG	Sustainable development goal
SME	Small and medium-sized enterprise
STEM	Science, technology, engineering and mathematics
TDI	Technology and digital intensive
TVET	Technical and vocational education and training
UNIDO	United Nations Industrial Development Organization

Overview
Industrializing in the digital age

Advanced digital production technologies can foster inclusive and sustainable industrial development and the achievements of the SDGs

The emergence and diffusion of advanced digital production (ADP) technologies—artificial intelligence, big data analytics, cloud computing, Internet of Things (IoT), advanced robotics and additive manufacturing, among others—is radically altering the nature of manufacturing production, increasingly blurring the boundaries between physical and digital production systems. Under the right conditions, the adoption of these technologies by developing countries can foster inclusive and sustainable industrial development (ISID) and the achievement of the Sustainable Development Goals (SDGs).

Only a few economies and firms are creating and adopting ADP technologies

The creation and diffusion of ADP technologies, however, remains concentrated globally, with only weak development in most emerging economies. The Industrial Development Report (IDR) 2020 finds that 10 economies—the frontrunners—account for 90 percent of all global patents and 70 percent of all exports directly associated with these technologies. Another 40 economies—the followers—actively engage in these technologies, though with much more modest intensity. The rest of the world either shows very little activity (the latecomers) or fails to take part in the global creation and use of these technologies (the laggards).

But ADP technologies open new opportunities for catching up

ADP technologies do open new opportunities for catching up, but exploiting them requires a minimum base of industrial capabilities. A clear positive relationship exists between the roles of different economies as frontrunners, followers, latecomers and laggards in the creation and use of these technologies and their average industrial capabilities. Greater engagement with these technologies is associated with higher rates of growth in manufacturing value added (MVA), driven mainly by faster productivity gains. And contrary to common thinking, developing countries actively engaging with ADP technologies also present positive employment growth.

Why should we care about new technologies?

Technologies drive ISID through new products and new processes

New technologies and inclusive and sustainable industrial development

New technologies are at the core of successful ISID. They enable the creation of new goods, which leads to the emergence of new industries. And they support an increase in production efficiency, which brings prices down and opens consumption to the mass market —or increases profits, with possible follow-on effects for investment (Figure 1). In the right context, new technologies can also promote environmental sustainability and social inclusion.

New industries come from new technologies

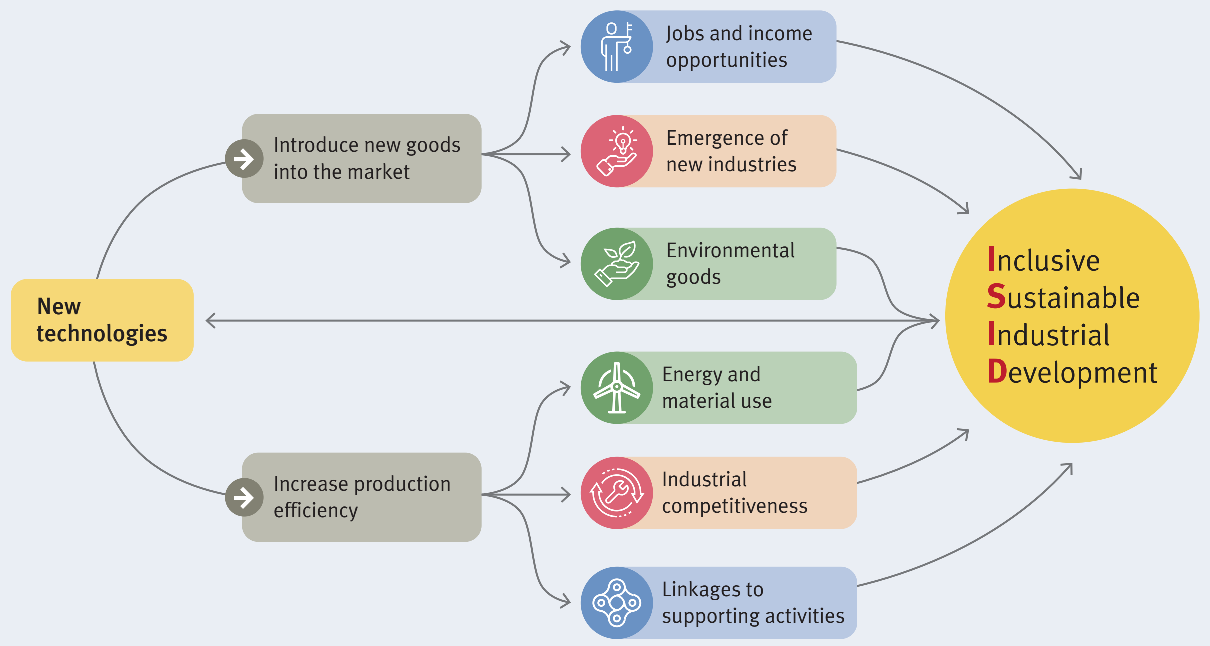
New technologies can lead to product innovations, resulting in the emergence of new industries—and the jobs and incomes associated with them. This supports industrialization and social inclusion. When these innovations are geared to reducing environmental impacts—by introducing *green* manufacturing—they also promote the environmental sustainability of the industrial process.

Industrial competitiveness ultimately depends on technological upgrading

New technologies can also increase production efficiency, which is key to sustaining and fostering industrial competitiveness and, through this channel,

New technologies are at the core of successful ISID

Figure 1
New technologies and inclusive and sustainable industrial development



Note: The upper part of the figure shows how new technologies drive inclusive and sustainable industrial development (ISID) by introducing new goods into the market. The lower part shows how new production technologies also contribute to ISID by increasing production efficiency. As industrialization evolves, the innovative potential of countries also increases. This is shown by the straight arrow going from right to left.
Source: UNIDO elaboration.

expanding manufacturing production. In many cases, the very application of new technologies requires additional inputs and services from other sectors of the economy, thus increasing the multiplier effects of industrial development outside the boundaries of the factory. Greater efficiency is associated with reductions in pollutant emissions and material and energy consumption per unit of production, which can improve the environmental sustainability of the process.

What are the new technologies shaping the industrial landscape?

First came the steam, electricity and computing-driven industrial revolutions

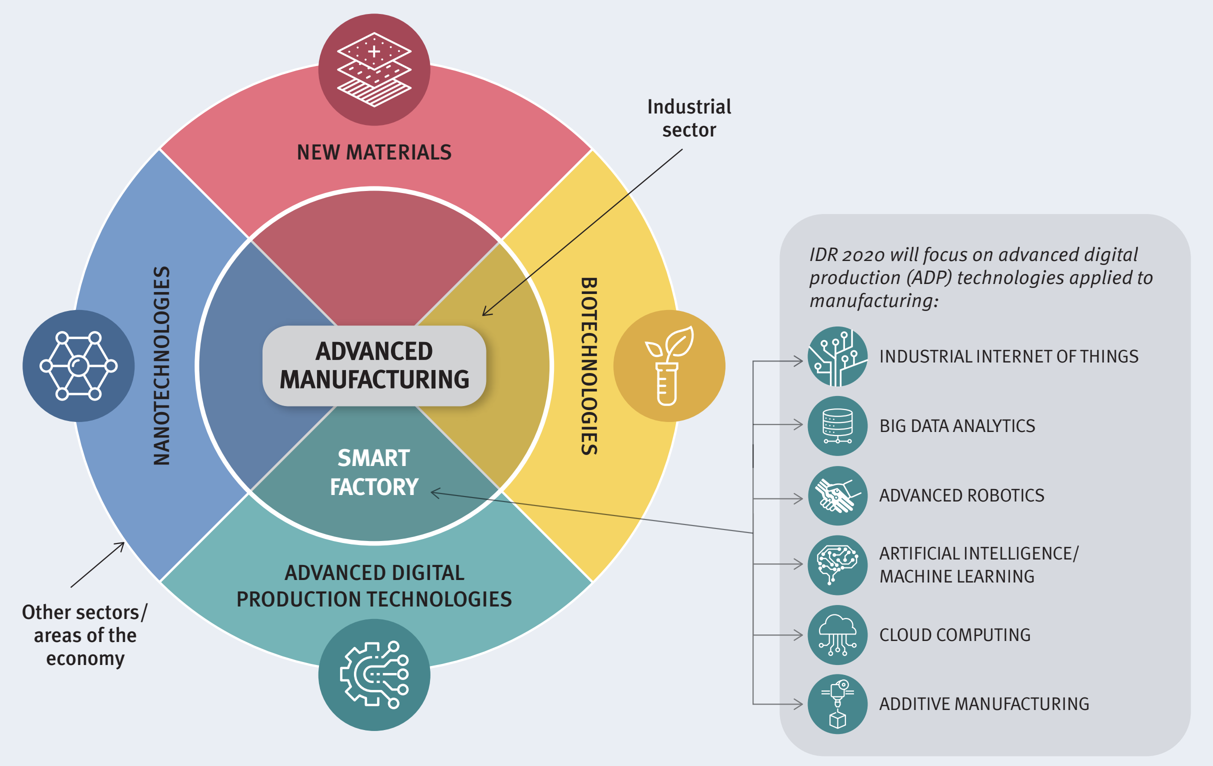
Different waves of technological advancements have pushed economic development since the first industrial revolution (1IR). The invention of the steam engine, the mechanization of simple tasks and the construction of railroads triggered the 1IR between 1760 and 1840. The advent of electricity, the assembly line and mass production gave rise to the second industrial revolution (2IR) between the late 19th and early 20th century. The development of semiconductors and mainframe computing in the 1960s, together with personal computers and the internet, were the main engines of the third industrial revolution (3IR).

Yet another wave is making its mark on the industrial landscape

Recent technological breakthroughs seem to be pushing yet another wave, in what is commonly called the fourth industrial revolution (4IR). The concept is based on the growing convergence of different emerging technology domains—digital production technologies, nanotechnologies, biotechnologies and new materials—and their complementarity in production (Figure 2). Advanced manufacturing is the term typically used to denote the adoption of these technologies

ADP technologies give rise to smart manufacturing production systems

Figure 2
Broad technological domains of the fourth industrial revolution



Source: UNIDO elaboration based on OECD (2017), Schwab (2016), UNCTAD (2018), UNESCAP (2018) and UNIDO (2017).

in manufacturing production. In the particular case of ADP technologies, their application to manufacturing gives rise to smart manufacturing production systems—also known as the smart factory or Industry 4.0. Smart production entails the integration and control of production from sensors and equipment connected in digital networks, as well as the fusion of the real world with the virtual—in so-called cyber-physical systems (CPSs)—with support from artificial intelligence. The shift to smart manufacturing production is expected to leave a long-lasting mark on the industrial landscape.

An evolutionary transition to ADP technologies

Technologies of the fourth industrial revolution arise from traditional industrial production

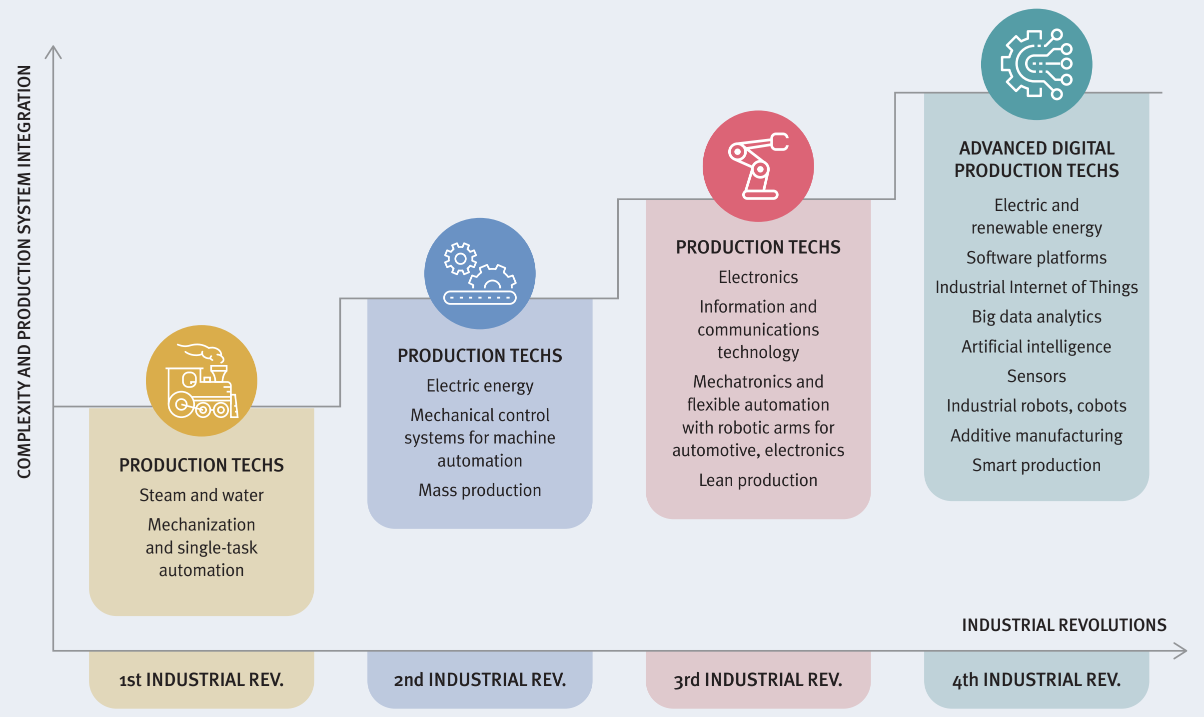
ADP technologies are the last in the evolution of traditional industrial production technologies (Figure 3). In fact, many of these technologies have evolved and emerged from the same engineering and organizational principles of previous revolutions, suggesting an “evolutionary transition” more than a “revolutionary disruption.” For instance, automating processes go back to the 1IR, while the adoption of robots goes back at least to the 1960s (Andreoni and Anzolin 2019).

ADP hardware is a mix of old and new

ADP technologies result from the combination of three main components—hardware, software and connectivity (Figure 4). The hardware components are made of tools, tooling and the complementary equipment of modern industrial robots and intelligent automated systems, as well as cobots (robots co-operating with workers in the execution of tasks) and 3D printers for additive manufacturing. This set of hardware production technologies is largely similar to its

History's technological revolutions have divided the world into leading and following economies

Figure 3
Production technologies: From the first industrial revolution to the fourth



Source: Andreoni and Anzolin 2019.

predecessor in the 3IR. What makes these machines different is their connectivity and their flexibility and functionality in executing productive tasks.

ADP connectivity is a big change from older manufacturing

Connectivity in ADP technologies is achieved through the sensors in hardware, made possible by equipping machines and tools with actuators and sensors. Once machines and tools are able to sense the production process and products—their components, material and functional properties—they are also able to collect and transmit data through the industrial IoT. This type of connectivity opens the way for a paradigm shift from centralized to decentralized production.

Connectivity leads to smart networked systems

Production technologies become fully digital once their connectivity is enhanced by software, allowing big data analytics—that is, tools able to process vast quantities of data in near-real time. Building on computer-aided manufacturing (CAM), computer-integrated manufacturing (CIM) and computer-aided design (CAD) together with the improvements offered by information and communications technology (ICT) during the 3IR, the software of the 4IR has opened the way for cyber-physical systems. These are smart networked systems with embedded sensors, processors and actuators, designed to sense and interact with the physical world and support, in real time.

Who is creating, and who is using ADP technologies?

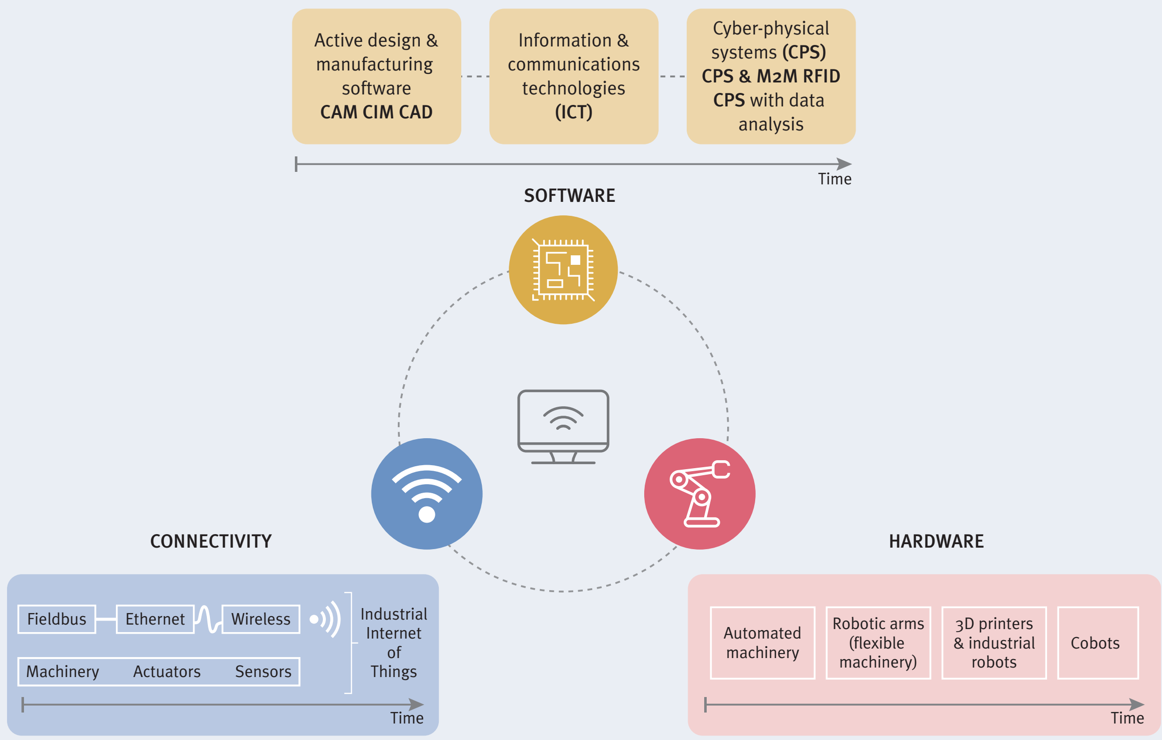
A concentrated global landscape

Industrial revolutions have leading and following economies

History's technological revolutions have divided the world into leading and following economies,

"Ten economies account for 91 percent of global patenting in ADP technologies

Figure 4
Building blocks of ADP technologies



Note: CAM is computer-aided manufacturing, CAD is computer-aided design, CIM is computer-integrated manufacturing, M2M is machine to machine, and RFID is radio-frequency identification. CIM links CAD, CAM, industrial robotics, and machine manufacturing through unattended processing workstations.
Source: Andreoni and Anzolin 2019.

depending on their involvement in creating and using the emerging technologies. In many cases, however, important parts of the world remained completely excluded from the ongoing revolution, entering only after several decades, when the technologies became cheap enough and the capability gap narrowed. A major concern at the onset of a new revolution is the extent to which all countries—especially those still trying to develop basic industrial capabilities—will be integrated into the emerging technological landscape.

The very top economies express the most ADP activity

Today's technological breakthroughs in ADP are again dividing the world between leaders, followers and laggards. One striking feature of the creation and diffusion of ADP technologies is the extreme concentration, especially of patenting and exporting activity. In the distribution of both patenting and exporting, the average is extremely high relative to the median, and only a few economies are above it. So, the top economies (those above the average) explain most of the world activity in each area.

Ten frontrunner economies account for 90 percent of patents and 70 percent of exports

Only 10 economies show above-average market shares in the global patenting of ADP technologies.[1] Ordered by their shares, these economies are the United States, Japan, Germany, China, Taiwan Province of China, France, Switzerland, the United Kingdom, the Republic of Korea and the Netherlands (Table 1). Together, they account for 91 percent of all global patent families. This group leads the rest of the world in creating new technologies within the ADP technology field. They not only invent the new technologies

> **Only 50 economies can be considered as actively engaging with ADP technologies**

Table 1
From laggards to frontrunners in the emerging technological landscape

Group		Short description	Criteria
Frontrunners (10 economies)		Top 10 leaders in the field of ADP technologies	Economies with 100 or more global patent family applications in ADP technologies (average value for all economies with some patent activity in this field)
Followers in production (23 economies)	As innovators	Economies actively involved in patenting in the field of ADP technologies	Economies with at least 20 regular patent family applications, or 10 global patent family applications in ADP technologies (average values for all economies with some patent activity, once frontrunners are excluded)
	As exporters	Economies actively involved in exporting ADP-related goods	Economies relatively specialized in exporting ADP-related goods that sell large volumes in world markets (above the average market share once frontrunners are excluded)
Followers in use (17 economies)	As importers	Economies actively involved in importing ADP-related goods	Economies relatively specialized in importing ADP-related goods that purchase large volumes in world markets (above the average market share once frontrunners are excluded)
Latecomers in production (16 economies)	As innovators	Economies with some patenting activity in ADP technologies	Economies with at least one regular patent family application in ADP technologies
	As exporters	Economies with some exporting activity of ADP-related goods	Economies that either show relative specialization in exporting ADP-related goods or sell large volumes in world markets (above the average market share once frontrunners are excluded)
Latecomers in use (13 economies)	As importers	Economies with some importing activity of ADP-related goods	Economies that either show relative specialization in importing ADP-related goods or sell large volumes in world markets (above the average market share once frontrunners are excluded)
Laggards (88 economies)		Economies showing no or very low engagement with ADP technologies	All other economies not included in the previous groups

Economies actively engaging with ADP technologies

Note: The characterization is for 167 economies that, according to the United Nations Statistical Division, had more than 500,000 inhabitants in 2017. See Table A1 in the Annex for the economies in each category.
Source: UNIDO elaboration.

but also sell (and purchase) in global markets the goods embodying these technologies—they account for almost 70 percent of global exports and 46 percent of global imports. These economies are the frontrunners in ADP technologies.

40 economies are following, but with lower values

Other economies are also engaging in the new technologies, though with lower values. Israel, Italy and Sweden, for instance, show large shares of global patents, whereas Austria and Canada have high values of exports. By the same token, Mexico, Thailand and Turkey have high values of imports. These economies are followers in this technology race. Looking at the average values of patent, exports and imports indicators once the frontrunners are excluded, the report identifies 40 economies that would fall into this category. These economies explain 8 percent of global patents and almost half of all imports of goods embodying these technologies.

The rest of the world shows low or very low to no activity in this field

Taken together, only 50 economies (the frontrunners and followers) can be considered as actively engaging with ADP technologies. They are either producing or using these technologies to an extent captured by country statistics. The remaining economies show low (latecomers) or very low to no activity (laggards) in the field.

> **“In most countries, different generations of digital technology applied to manufacturing coexist**

Within countries, only a handful of firms are fully adopting ADP technologies

The 4IR affects a small portion of the economy in most countries

The global characterization just presented is confirmed when looking at the industrial sector of individual countries. In most countries, different generations of digital technology applied to manufacturing production coexist, and those associated with the 4IR have permeated only a small part of the sector.

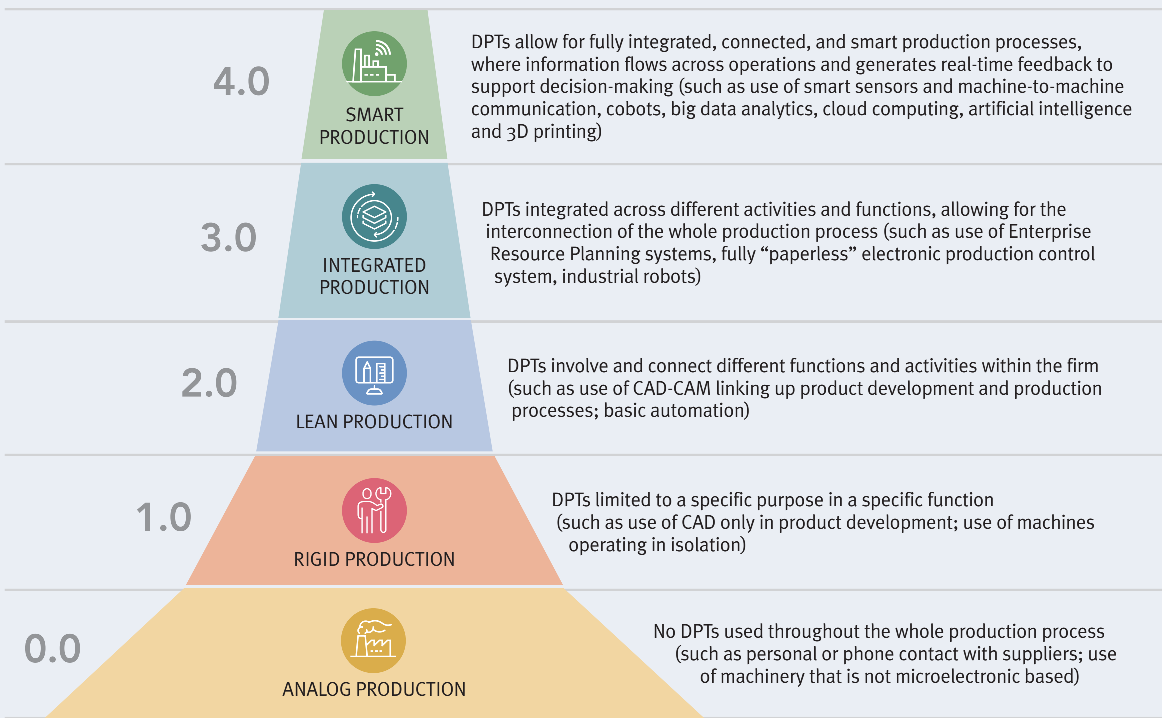
Developing countries retrofit 4IR technologies to incomplete 3IR systems

Firms in developing countries still use—often ineffectively—3IR technologies. Their lack of command of 3IR technologies—basic automation and ICTs—also makes it difficult for them to fully engage with the opportunities of ADP technologies and the 4IR. The main opportunities for these countries lie, therefore, in the gradual integration of these technologies within existing 3IR production systems, retrofitting production plants in areas of the firm where integration is possible (Andreoni and Anzolin, 2019).

Different technological generations coexist

Building on the idea that at any given point in time firms in different countries are likely to use a combination of digital technologies emerging from different technological paradigms beyond the analog, IDR 2020 identifies four generations of digital manufacturing production based on their increasingly sophisticated use of digital technologies in production (Figure 5).[2]

Figure 5
Four generations of digital production technologies applied to manufacturing



Note: DPT is digital production technology, CAD is computer-aided design, and CAM is computer-aided manufacturing.
Source: UNIDO elaboration based on Kupfer et al. (2019).

Only a handful of manufacturing firms are adopting ADP technologies

As many as 70 percent of firms are still in analog production

The bottom of the pyramid represents an initial stage of production where digital technologies are not used in any area of the firm. This seems to be the reality in least developed countries (LDCs) and low-income economies. Most of the manufacturing sector in countries defined as laggards fall into this category. In Ghana, for instance, almost 70 percent of firms surveyed for this report fall in the analog category. Once firms start adopting digital technologies, four generations are distinguished. The first, rigid production, is characterized by the use of digital applications for specific purposes only and in isolation from each other. The second, lean production, refers to the semi-flexible automation of production with the aid of digital technology, accompanied by a partial integration across different business areas. The third, integrated production, entails using digital technologies across all business functions. The fourth and final mode is characterized by the use of digital technologies with information feedback to support decision-making.

Moving to the next generation requires big changes

Generation 1.0 and generation 2.0 have been around for as long as numerical control programming systems have existed (late 1950s), though devices such as CAD have evolved exponentially in recent years thanks to parametric engineering. Even if efficiency and quality of processes are substantially improved, evolving from generation 1.0 to generation 2.0 does not require major organizational changes. But evolving from generation 2.0 to generation 3.0 requires substantial changes—to fully integrate organizational functions, with comprehensive and effective standardization of processes and information systems. Generation 4.0 implies the use of ADP technology-based solutions, such as advanced communications devices, robotization, sensorization, big data and artificial intelligence.

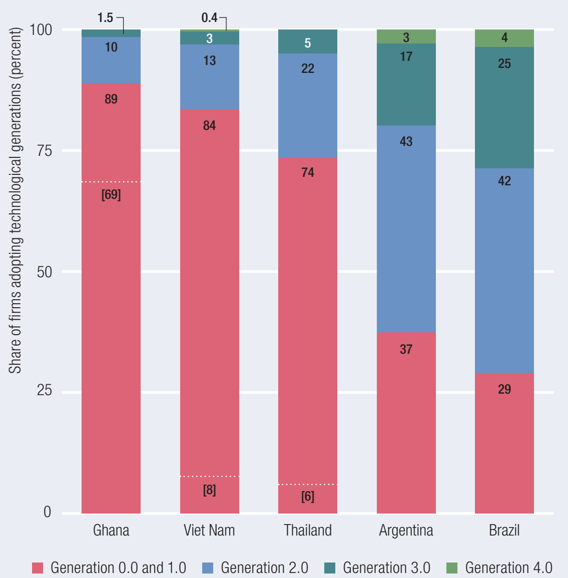
Few firms use the most advanced technologies

Evidence collected for five countries show that only a handful of manufacturing firms are adopting ADP technologies (Figure 6). Despite large cross-country differences, in all countries surveyed, the diffusion of the highest generations of digital technologies (generations 3.0 and 4.0) is incipient: adopters represent a niche, ranging from 1.5 percent in Ghana to about 30 percent in Brazil. The survey results also show how different generations of technologies coexists within developing countries, creating "technological islands," where a few firms with advanced technologies are surrounded by a majority of firms operating at a much lower technological level.

Leapfrogging into the 4IR depends on country and industry conditions

A key question for countries where most manufacturing firms lie far below the frontier—concentrated somewhere between analog and generation 1.0—is how can they move up in the technological ladder. In particular, can these firms skip some generations or directly leapfrog to the most advanced? Differences

Figure 6
Adoption of ADP technologies is still limited among developing countries



Note: Numbers in brackets are generation 0.0 firms. For Argentina and Brazil no information on generation 0.0 is available due to the structure of their survey questionnaires.
Source: UNIDO elaboration based on data collected by the UNIDO firm-level survey "Adoption of digital production technologies by industrial firms" (for Ghana, Thailand and Viet Nam) and Albrieu et al. (2019) and Kupfer et al. (2019) (for Argentina and Brazil).

“Some manufacturing industries are more likely to adopt ADP technologies

in capabilities, endowments, organizational characteristics and technological efforts, as well as domestic infrastructural and institutional conditions explain why some firms (and countries) succeed in ascending the ladder and others do not.

New technology diffusion is also concentrated by industry and size

The diffusion of ADP technologies is uneven across industries

Differences in technological intensity and production processes make some manufacturing industries within a country more likely to adopt ADP technologies. Two industries stand out: computer and machinery and transport equipment. These industries show above-average adoption of key ADP technologies (Figure 7). The computer and machinery industry has the highest use of cloud computing and 3D printing technologies, 10–15 percentage points above average, while the transport equipment industry is ranked second and is top for the use of industrial robots in manufacturing. As ADP technologies continue their broad-based diffusion, other industries (even with low technology intensity) might also take the lead in the adoption of these technologies.

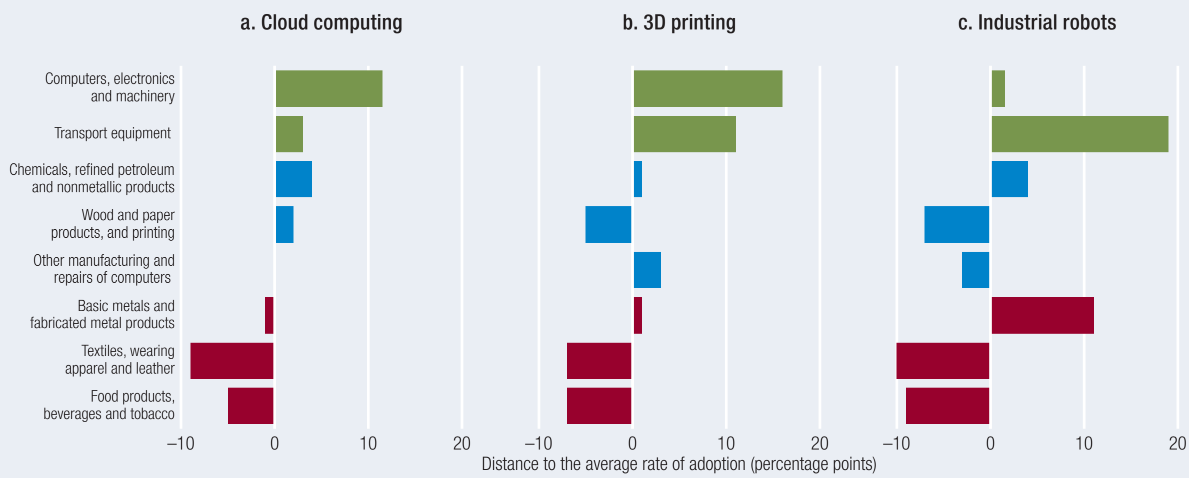
Frontrunners and followers tend to specialize in these industries

The stronger engagement of frontrunners and followers with ADP technologies also stem from the fact that they have a much higher share of technology- and digital-intensive (TDI) industries (comprising computer and machinery and transport equipment) in their MVA. These industries gained in importance especially after 2005, the year after which the diffusion of ADP technologies took off. Such superior performance is strongly driven by productivity growth. However, the story of their development is not about the substitution of the new technologies for labour —it is more about the contribution of these technologies to their competitiveness and expansion, which made the development process inclusive, thanks to the growth of both productivity and employment.

Larger firms adopt more ADP technologies

Size also matters when it comes to ADP technology. Large firms, thanks to—but not only to—the larger

Figure 7
Rates of adoption of key ADP technologies differ across industries in Europe



Note: All values are for 2018 and are aggregates for the 28 countries of the European Union. Rate of adoption is defined as the percentage of firms in an industry using a chosen technology. Due to data availability, chemicals is presented together with refined petroleum and non-metallic products (ISIC codes 19 to 23). The colours of the bars reflect the technology and digital intensity classification of industries. Green = TDI industries (industries that are simultaneously intensive on digitalization and technology). Blue = industries that are intensive on either digitalization or technology but not on both. Red = industries that are intensive on neither digitalization nor technology. The bars show the distance from the average rate of adoption in all manufacturing industries, in percentage points.
Source: UNIDO elaboration based on Eurostat (2019).

> To engage with ADP technologies, developing economies must build industrial capabilities

investments their resources permit, tend to enjoy technological and productive capabilities that make them more likely to adopt the new technologies. Data on the five countries surveyed for this report support this argument since a higher share of larger firms adopt the highest generations of digital production technologies (generations 3.0 and 4.0). In Argentina, for instance, the adoption rate within large firms (more than 100 employees) is 20 percentage points higher than the average rate of adoption. Nonetheless, in some cases (such as Thailand) the penetration of new technologies can also be strong in small firms.

What is needed to engage with ADP technologies?

Engaging requires industrial capabilities at the country level

Developing countries face five broad challenges

The vast majority of developing countries are far from becoming established players in this field because they face specific challenges in engaging with the new technologies. These challenges can be grouped under five broad headings (Andreoni and Anzolin, 2019):

- *Basic capabilities.* The production capabilities required for absorbing, deploying and diffusing ADP technologies along the supply chains are scarce and unevenly distributed. These technologies have also raised the "basic capability threshold," not because they are entirely new but because they imply the fusion of new and existing technologies into complex integrated technology systems.
- *Retrofitting and integration.* Companies in developing countries that could make technology investments in this area have already committed resources to older technology, and they need to learn how to retrofit and integrate the new digital production technologies into their existing production plants. Setting up brand new plants is rarer because it requires significant long-term investment and access to markets.
- *Digital infrastructure.* These technologies demand substantial infrastructure for use in production. Some developing countries face significant challenges in providing affordable and high-quality electricity as well as reliable connectivity. These and other infrastructure bottlenecks might make technology investments by individual firms too risky and financially unviable.
- *Digital capability gap.* In many developing countries, companies engage with some ADP technologies, but many of these technologies remain contained within the company and, occasionally, a few close suppliers who have the basic production capabilities to use them. Around these 4IR islands, the vast majority of firms still use technologies typical of the 3IR or even 2IR. In this context, it is extremely difficult for the leading companies to link backwards and nurture their supply chains. When this digital capability gap is extreme, the diffusion of ADP technologies remains very limited.
- *Access and affordability.* These technologies tend to be controlled by a limited number of countries and their leading firms. Developing countries rely dramatically on importing these technologies and in many cases, even when they can mobilize the resources to access them, they remain dependent on providers for hardware and software components.

To engage with ADP technologies, developing economies must build industrial capabilities

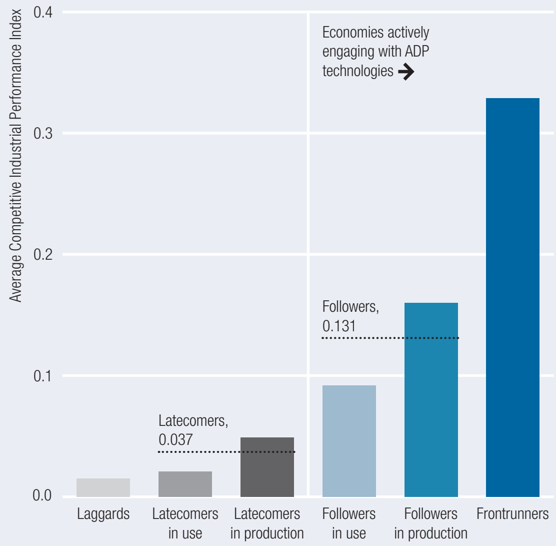
Taken together, these challenges point in one direction—the need to build basic industrial production capabilities as a prerequisite to entering the 4IR. In fact, the differences in engagement with ADP technologies reflect the global heterogeneity of industrial capabilities: frontrunners tend to have larger industrial capabilities than followers, followers larger capabilities than latecomers and latecomers larger capabilities than laggards. In each group, a clear distinction can also be made based on production (innovating and exporting), which requires greater industrial capabilities than use.

“The industrial capabilities of a country ultimately depend on the capabilities of firms

Industrial capabilities distinguish frontrunners and followers from latecomers and laggards

In 2017, the frontrunners presented an average Competitive Industrial Performance (CIP) index much higher than all other country groups (Figure 8). UNIDO's CIP index reflects the industrial performance of countries and thus can be a proxy for their underlying industrial capabilities—higher CIP should be associated with stronger industrial capabilities. The followers in production had an average CIP half that of the frontrunners, but higher than that of followers in use. Followers also show larger CIP values than latecomers, who rank higher than laggards. Each category has an average CIP value larger than the previous one, illustrating the stairway of industrial capabilities that countries need to climb in order to engage and upgrade roles in the use and production of ADP technologies.

Figure 8
Engaging with ADP technologies requires increasing industrial capabilities



Note: Average Competitive Industrial Performance index values for 2017.
Source: UNIDO elaboration based on the Competitive Industrial Performance Index 2019 database (UNIDO 2019a) and dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018).

Industrial capabilities are built in manufacturing firms

Firm capabilities are preconditions for adopting new technologies

The industrial capabilities of a country ultimately depend on the capabilities of firms. So, the diffusion of ADP technologies depends on firms acquiring the necessary capabilities—executable routines or procedures for repeated performance in a specific context, produced by learning in an organization (Cohen et al. 1996). Many different capabilities are needed to engage with ADP technologies, but acquiring them is not an easy or linear process.

Investment, technology and production capabilities are crucial for adopting and using new technology

Investment and technology capabilities enable a firm to deal with technological change. They include the technological knowledge, resources and skills firms need to adopt and use equipment and technology, expand output and employment and further upgrade their technological competence and business activities. Production capabilities are related to experience, learning by doing and the behaviours of entrepreneurs related to production. These capabilities represent the first step for firms to acquire the base needed for further technology improvements.

Capabilities are accumulated gradually

Acquiring capabilities is often a gradual process, as firms and countries first industrialize and acquire basic capabilities, then upgrade towards higher levels of technology. Distinguishing developing country firm capabilities into basic, intermediate and advanced expresses the incremental steps for companies to accumulate capabilities over time (Table 2). Companies must go through this process to capture the opportunities offered by ADP technologies and to remain competitive and innovative.

Basic production capabilities remain critical

Mastering the basic capabilities—often associated with production—–is critical for effectively deploying new technologies and retaining efficiency. Even the simplest productive activities often require the

> **“In developing countries, a large number of low-capability actors coexists with more advanced ones**

Table 2
Accumulating investment, technology and production capabilities for advanced digital production

		Investment	Technology	Production
BASIC	Simple, routine-based	Feasibility study Basic market and competitors analysis Basic finance and financial flow management	External sourcing of information (for example from suppliers, industry networking, public information) Basic training and skills upgrading Recruitment of skilled personnel	Plant routine coordination Routine engineering Routine maintenance Minor adaptation of production processes and process optimization Basic product design, prototyping and customization Product and process standards compliance, product quality management Quality management Basic bookkeeping Basic packaging and logistics Basic advertising Supplier monitoring Basic export analysis and some links with foreign buyers
INTERMEDIATE	Adaptive, based on search, experimentation, external cooperation	Seizing market opportunities Search for equipment and machinery Procurement of equipment and machinery Contract negotiation Credit negotiation	Seizing technology opportunities Technology transfer Technological collaboration with suppliers/buyers (downstream and upstream) Vertical technology transfer (if in global value chain) Linkages with (foreign) technology institutions Licensing new technology and software Alliances and networks abroad Formal process of staff recruitment Formalized training, retraining and reskilling Software engineering, automation and information and communications technology skills	Routinized process engineering Preventive maintenance Adaptation/improvement of externally acquired production technology Introduction of externally developed techniques Process remodularization and scaling up Reorganisation of workforce Reverse engineering (product) Product design improvement Product life-cycle management Quality certification Productivity analysis Auditing Inventory control Dedicated marketing department Basic branding Supply chain/logistics management Systematic analysis of foreign markets

activation and matching of interdependent clusters of capabilities. The development of these capabilities is related to the existence of an industrial ecosystem in which industrial firms can operate and learn.

Each company has a “unique bundle of capabilities”

As different companies face different learning challenges, their pace of developing new capabilities is likely to be uneven (Andreoni and Anzolin 2019). In developing countries in particular, this unevenness reinforces firm heterogeneity, with a large number of low-capability and low-performance actors coexisting with more advanced ones. This divide between the most advanced companies and the rest has been defined as the digital capability gap.

The digital capability gap may harm both advanced and low-capability firms

The gap’s direct consequence is the creation of the 4IR islands observed in Figure 6—a few major

“The gap turns a technology upgrading opportunity into a digital industrialization bottleneck

Table 2 *(continued)*

Accumulating investment, technology and production capabilities for advanced digital production

		Investment	Technology	Production
ADVANCED	Innovative, risky, based on advanced forms of collaboration and R&D	World-class project management capabilities Risk management Equipment design	Research in process and product, R&D Formal training system Continuous links with R&D institutions and universities, cooperative R&D Innovative links with other firms and market actors Licensing own technology to others Open innovation ecosystem	Process engineering Continuous process improvement New process innovation New product innovation Mastering product design Advanced organizational capacity for innovation World-class industrial engineering, supply chain and logistics Inventory management Brand creation and brand deepening Advanced distribution system and coordination with retailers/buyers Own marketing channels and affiliates abroad Foreign acquisition and foreign direct investment
ADVANCED	Production system integration capabilities	Seizing technology integration solutions Seizing organizational integration solutions Data analytics for decision-making and risk management	Integrated product and process R&D Advanced digital skills development Internal/own software platform development	Predictive and real-time maintenance Cyber- physical systems for virtual product/process design Technological and organizational integration Agile and smart production Digital and automated inventory control Real-time production and supply chain data Fully integrated information systems across all functions (for example, enterprise resource planning) Big data analytics throughout all production stages (product design, production, marketing, logistics…)
SYSTEMIC				
Enabling institutional and infrastructure capabilities	Reliable energy supply Reliable connectivity Bandwidth connectivity infrastructure (ethernet and wireless) Digital technology institutions infrastructure Data ownership policy and software licensing accessibility			

Source: UNIDO elaboration based on UNIDO (2002) and Andreoni and Anzolin (2019).

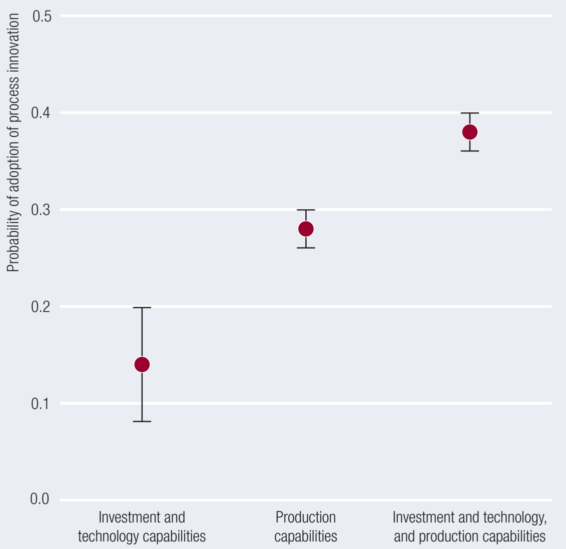
leading companies engaged with ADP technologies operating as islands in a sea of firms without capabilities and still using outdated technologies. Leading firms may be harmed by the gap, because they have trouble linking backwards and nurturing their supply chains. Thus, the gap turns a technology upgrading opportunity into a digital industrialization bottleneck.

Engaging in industrial production is key to closing the gap

Policy debates tended to focus mostly on investment and technology capabilities. IDR 2020 shows that production capabilities are also of prime importance. An analysis of the determinants of adopting new technologies shows that production capabilities are the most important ones (Figure 9). These capabilities can be acquired only through past experience in industrial production.

❝ **Participation in GVCs positively affects the probability of adopting new technologies**

Figure 9
Production capabilities are key for the adoption of technological process innovation



Note: The analysis includes 13 African economies (Democratic Republic of Congo, Ghana, Kenya, Malawi, Namibia, Nigeria, Rwanda, South Sudan, Sudan, the United Republic of Tanzania, Uganda, Zambia and Zimbabwe) and four South Asian economies (Bangladesh, India, Nepal and Pakistan). Only manufacturing firms are considered. The graph depicts coefficients and confidence intervals (at 95 percent) for the average marginal effects of the variables of interest on the probability of adopting a process innovation. A linear probability model was implemented, with bootstrapped standard errors. Country and sector dummies are included.
Source: UNIDO elaboration based on Bogliacino and Codagnone (2019) derived from World Bank Enterprise Survey (Innovation Follow-up, 2013–2014).

Combined, the investment, technology and production capabilities lead to innovation

Investment and technology capabilities fully disclose their importance when combined with production capability variables. Production capabilities are more important to explain the adoption of technology. This does not mean that investment and technology variables do not matter. Combined, investment, technology and production capabilities delivered a premium of higher adoption rates of new processes technologies compared with firms where only one of the two categories of capabilities is present.

Firm participation in global value chains is associated with using ADP technology

For manufacturing firms in developing and emerging industrial economies, learning about ADP technologies may also depend on their integration in international trade and production networks. International trade and production networks can be viable channels for knowledge transfer to suppliers downstream in a global value chain (GVC). Evidence from the countries surveyed for this report confirms that participation in GVCs positively affects the probability of adopting new technologies.[3] This positive correlation holds when controlling for other factors likely to shape the adoption of new production technologies, such as size, sector, human capital and R&D and machinery investments. Integration in manufacturing GVCs can represent an important opportunity for lagging countries to enter the ongoing technological race.

Engaging also requires specific skills in the labour force

ADP technologies require "skills of the future"

Technological change is not neutral when it comes to the skills demanded. The adoption of ADP technologies requires the development of skills complementary to the new technologies (Rodrik 2018). Three groups of skills (the "skills of the future") are particularly important for ADP technologies: analytical skills; specific technology-related skills, including science, technology, engineering and math (STEM)—and ICT-related skills; and soft skills. As the jobs created by new technologies are likely to be more demanding of new and technical skills, and analytic and cognitive abilities, the skills of future will provide the best safeguard against the risk of displacement by technology.

Firms with higher technological intensity have more STEM professionals

Greater demand for these skills is already reflected in the employment profile of firms with higher technological intensity. The shares of STEM employees are consistently higher among more technologically dynamic firms, which are engaging or ready to engage with ADP technologies. Moreover, these firms also recognize the growing importance of technology-related skills, such as human–machine interaction

> **ADP technologies can increase firm profits and capital use and improve environmental sustainability**

skills. Soft skills are also projected to become very important in the future. The reason may be that many new technologies require employees to work as well-integrated teams and to learn procedures and systems rapidly.

What dividends can ADP technologies deliver?

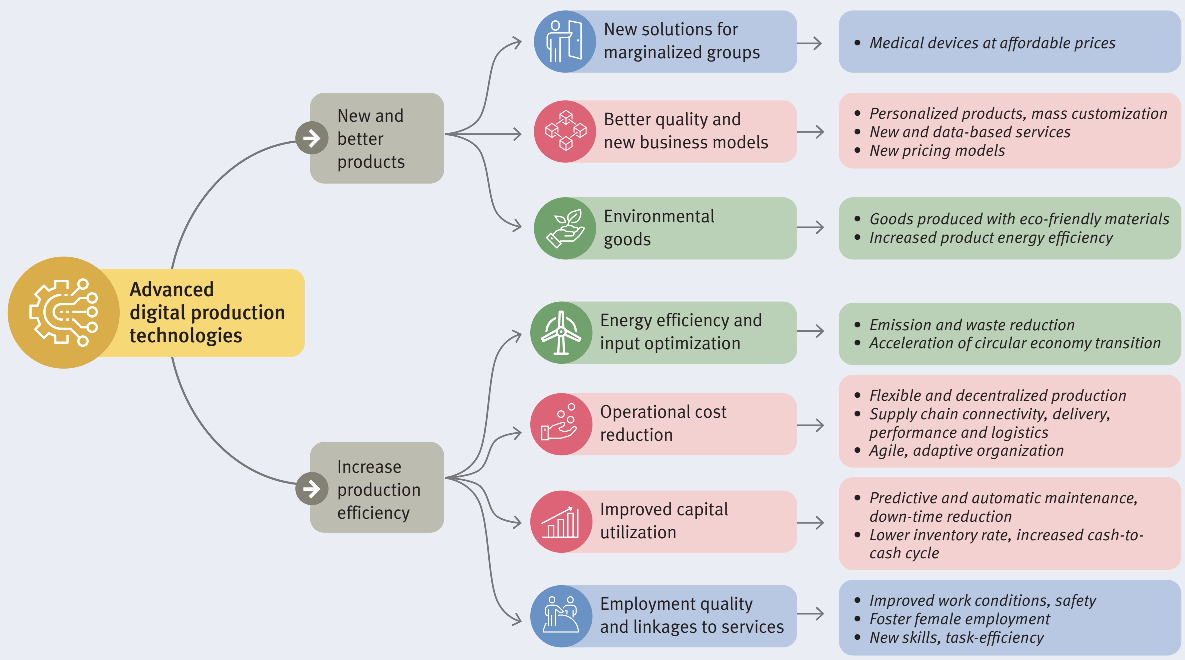
ADP technologies can improve profits, sustain the environment and expand the labour force

ADP technologies can increase firm profits and capital use, better integrate the labour force in production and improve environmental sustainability. Figure 10 summarizes the main mechanisms at play, following the conceptual framework at the beginning of the overview. The potential benefits that ADP technologies can bring in supporting ISID are again presented along two major channels: the introduction of new and better goods into the market—smart TVs, smart watches, home control devices and so on—and the increase of production efficiency through the digitalization and interconnectivity of production processes. Each of these broad channels directly affects the main dimensions of ISID: industrial competitiveness, environmental sustainability and social inclusion. The benefits also entail risks, and there is no guarantee that these effects will occur without other changes. Reaping the benefits depends on conditions specific to the countries, industries and firms involved in manufacturing production.

Expanded data analytics improve products and services

ADP technologies can enhance product–service characteristics and functionalities that would result in higher revenue improvement—including product innovation, customization and time to market—and a more competitive product–service package. Data analytics, for instance, allow taking advantage of collecting and analysing real-time customer data, enabling the direct involvement of customer demands and facilitating cost-effective mass customization of products. These insights into customer behaviour can provide enormous advantages for new products, services

Figure 10
Expected dividends from ADP technologies



Source: UNIDO elaboration based on Andreoni and Anzolin (2019).

> **Economies actively engaging with ADP technologies show much faster growth than the rest**

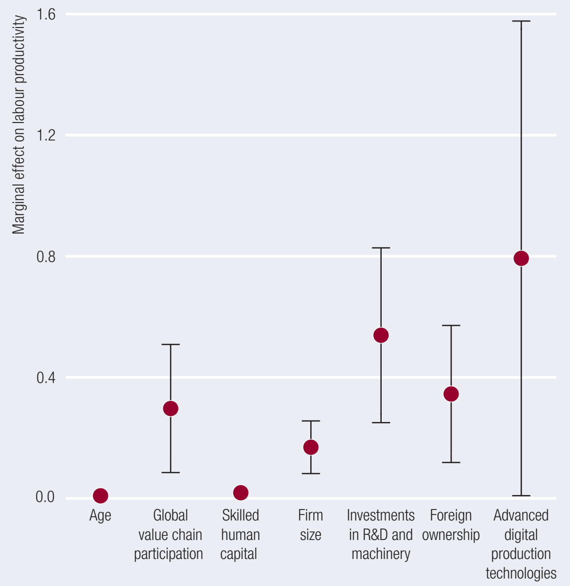
and solutions. The changes open new organizational and business model possibilities by attaching services to manufacturing production. In this way, ADP technologies open the possibility of revitalizing industrialization and boosting economic growth by creating new goods and by blending manufacturing and service activities.

Fostering productivity

Firms adopting advanced technology have higher productivity

Firms adopt ADP technologies to become more competitive and efficient. An econometric analysis conditional on other factors possibly affecting productivity of the countries surveyed for the report investigated whether firms with a higher level of digitalization were, on average, more productive than firms with lower levels (Figure 11). Even when controlling for a firm's age, investments in research and development and machinery, human capital and GVC participation, the adoption of ADP technology was positively and significantly associated with firm productivity. Technology adoption's coefficient is large compared with the coefficients of other important significant factors.

Figure 11
The adoption of ADP technologies is positively associated with productivity



Note: The graph depicts the coefficients and confidence intervals (at 90 percent) of the variables of interest on labour productivity, obtained implementing regression analysis on the firms surveyed in Ghana, Thailand and Viet Nam. The variable "Advanced digital production technologies" is a binary variable that takes the value of 1 if a firm is using generations 3.0 or 4.0 technologies, 0 otherwise. Country and sector dummies are included.
Source: UNIDO elaboration based on Pietrobelli et al. (2019) derived from the data collected by the UNIDO firm-level survey "Adoption of digital production technologies by industrial firms."

Frontrunners and followers lead in manufacturing value added growth due to productivity growth

What is true for the firms is also true for countries: economies actively engaging with ADP technologies —frontrunners and followers—show much faster growth of manufacturing value added (MVA) than the rest—latecomers and laggards (Figure 12). In low- and lower-middle income and high-income economies, frontrunners and followers have almost twice the growth rate of latecomers and laggards. In upper-middle income economies, the difference is more than 50 percent. Faster growth in MVA can be explained by more dynamic employment creation, faster productivity gains or both. The largest differences are observed in the productivity dynamics. Frontrunners and followers are clearly ahead in productivity growth. Interestingly, in developing countries—low- and lower-middle income and upper middle income—frontrunners and followers also show positive growth in employment during this period. In high-income economies, instead, productivity growth more than compensated for a net destruction of *direct* jobs.

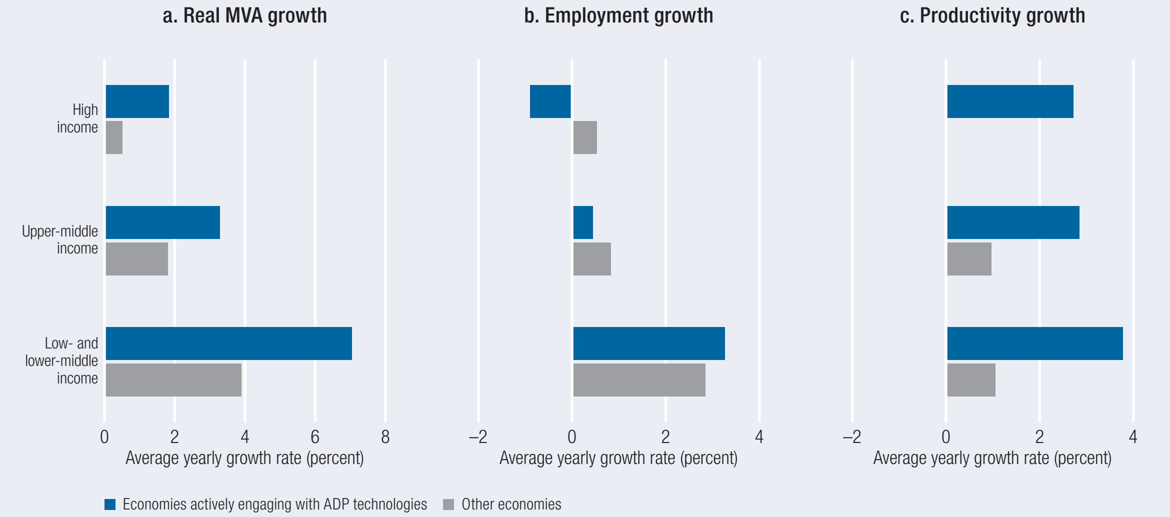
Strengthening intersectoral linkages

New technologies foster knowledge-intensive business services

The adoption of ADP technologies in manufacturing production requires additional support from other sectors of the economy, most notably knowledge-intensive services that provide the IT and digital solutions needed to implement smart production. This stronger interaction with services can potentially expand the multiplier effects of manufacturing production on job creation and

As countries deploy ADP technologies, knowledge-intensive business services play an increasing role

Figure 12
Economies active in ADP technologies grow faster than the rest, across all income groups



Note: Each panel shows the average yearly growth rate of the corresponding group and variable between 2005 and 2017. The analysis includes 166 economies (from which 50 are actively engaging with ADP technologies), which are classified according to World Bank's income group definitions for 2017: 73 low and lower-middle income economies (of which 4 are active); 44 upper-middle income economies (of which 13 are active), and 49 high income economies (of which 33 are active). Productivity is calculated as manufacturing value added in constant $ 2010 per number of workers.
Source: UNIDO elaboration based on the Manufacturing Value Added 2019 database (UNIDO 2019c), ILO (2018), and dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018).

poverty alleviation and open new windows of opportunity for countries to enter the manufacturing system.

Such services produce innovation and transmit new knowledge

Knowledge-intensive business services (KIBS) have an important role as producers of innovation and as carriers of new knowledge in an economy. They are mainly intermediate services (sold to other sectors rather than to final consumers), and through these linkages, they diffuse innovations along the value chain.

Frontrunners and followers tend to rely more on KIBS when producing industrial goods

The higher the income of the country group, the higher the share of KIBS in the value added generated by manufacturing, indicating the importance of knowledge-intensive inputs for the kinds of manufacturing activities undertaken by high-income economies. KIBS are not related just to country income levels. Across all income groups, the integration of KIBS is also larger in economies actively engaging with ADP technologies (Figure 13). As countries move to a higher level of engagement in developing and deploying ADP technologies, KIBS need to play an increasing role in manufacturing.

Creating jobs, not destroying them

Look beyond direct effects (workers displaced) to indirect and net effects

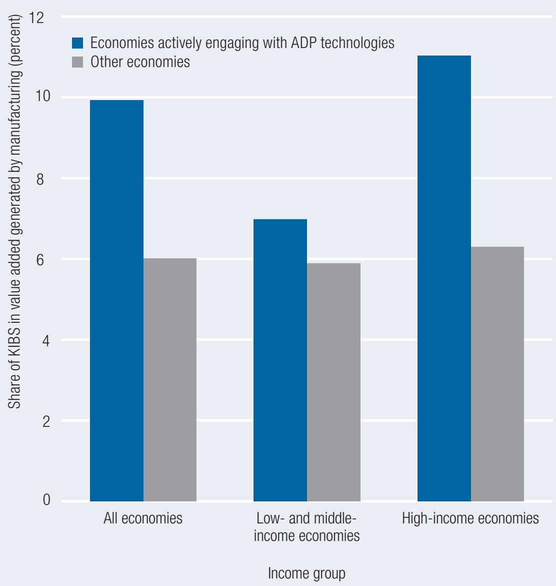
Concerns have been raised on the potential effect that ADP technologies can have in the labour market. But when evaluating the ultimate effect of a new technology (such as robots) on employment, all channels need to be considered. A sectoral or industry focus makes it difficult to assess the impact of technology on employment in the overall economy. So, it is necessary to analyse the direct and indirect macro effects of new technologies on employment. The indirect effects are based on both domestic and international linkages obtained from intercountry input-output tables.[4]

The indirect effects can outweigh the direct effects

To assess the impact of ADP technologies on employment, IDR 2020 finds that increasing the stock of

Increasing the stock of robots in one industry has indirect effects on the rest of the value chain

Figure 13
Manufacturing industries in economies actively engaging with ADP technologies are more integrated with KIBS, at all incomes



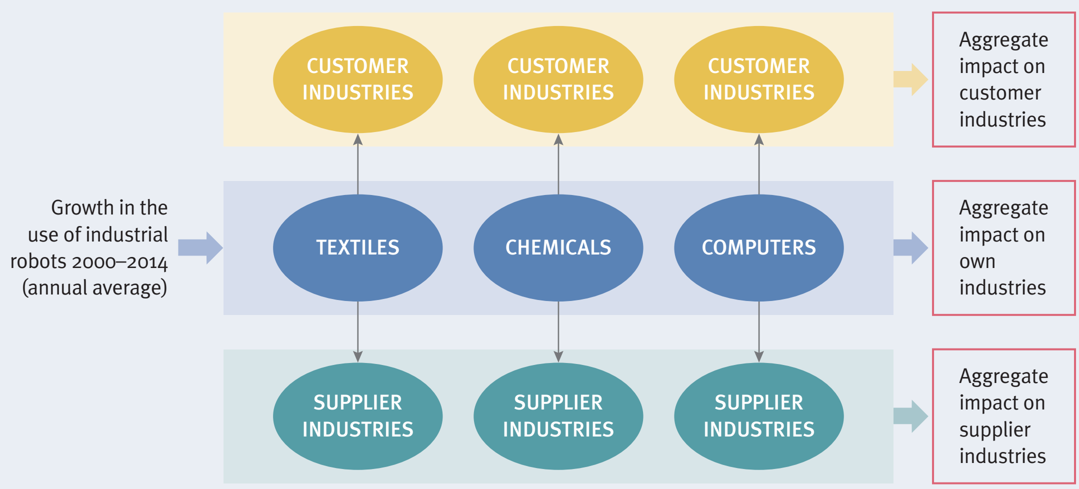
Note: Average values for the period 2005–2015. Manufacturing value added is in current $. The analysis includes 63 economies, which are classified according to World Bank's income group definitions for 2005: 30 low and middle income economies (of which 9 are active), and 33 high income economies (of which 24 are active). KIBS is knowledge-intensive business services.
Source: UNIDO elaboration based on Inter-Country Input-Output (ICIO) Tables (OECD 2018).

robots in one particular industry has a direct effect on the employment of that industry, but also indirect effects on the rest of the value chain (Figure 14). The increase in the use of robots in an industry has indirect effects on employment in customer and supplier industries. For example, the industry using more robots might produce intermediate products of better quality, sell at cheaper prices or both for its customer industries, which in turn could increase competitiveness and hire more workers to expand their businesses. That increase in the use of robots could also have an indirect impact on supplier industries because greater automation and changes in production processes could translate into greater demand for certain materials and components. Such a change in the demand emanating from a robotizing industry could have an impact on the employment of its supplier industries in either a positive or a negative way. At the same time, customers and suppliers can be located in the same economy (thus affecting domestic employment) or other economies (thus affecting foreign employment).

Between 2000 and 2014, the increase in industrial robots in manufacturing led to net job creation globally

Once all effects are considered, the contribution of annual growth in the stock of industrial robots to

Figure 14
Aggregate impact of the increase in industrial robot use in individual industries on world employment



Source: UNIDO elaboration.

“ Firms engaging with ADP technologies expect to increase— or at least keep—their employees

employment growth from 2000 to 2014 is positive, though very small. The main positive effects come from international supplier linkages and domestic customer linkages. Domestic supplier linkages, in contrast, show negative effects on employment. Interestingly, most of the jobs were created in emerging economies due to the increase in the stock of robots in industrialized economies.

Firms using robots can generate more jobs than firms not using them

This indicates the importance of taking into consideration the possibility for output growth due to robot adoption in addition to its effect on change in the production process (increasing capital intensity), relative to nonadopting firms. If greater use of robots makes production management easier and increases capital's income share relative to labour's without much contributing to the firm's or industry's higher competitiveness and output increase, robot adoption is likely to have a negative impact on employment. But if robot adopters are to experience much faster growth than nonadopters—due to increased production scales, intersectoral complementarity, redistribution of work in a value chain and relocation of workers within a firm—firms and industries adopting robots are likely to have a higher chance of generating jobs than those avoiding robots.

Technologically dynamic firms anticipate stable (or even greater) employment

The findings are in line with recent studies using long-term firm level and worker-level data that show that (at least in frontrunner economies, such as Germany) the adoption of robots has not increased the risk of displacement for incumbent manufacturing workers (Dauth et al. 2018). This is also confirmed at the micro level in the five countries surveyed for this report: the majority of firms engaging or ready to engage with ADP technologies expect to increase (or at least keep) their employees with the adoption of those technologies.

New technologies can also improve workers' conditions and involvement

ADP technologies also affect the social dimension of manufacturing production. They can improve workers' conditions in industrial production by introducing new workflows and task allocations, as well as increasing the skill threshold of the workforce. For instance, automation solutions in the automotive sector have offered opportunities for reorganizing production tasks, moving workers away from those most physically demanding. ADP technologies can also improve working conditions in manufacturing plants. Today's standard practice entails having workers manage advanced robots. The increased collaboration between humans and robots (or cobots) will create a blended workforce. Safety and tracking technologies also increase safety and improve working conditions on the shop floor.

Sustaining the environment

ADP technologies tend towards environmentally friendly solutions

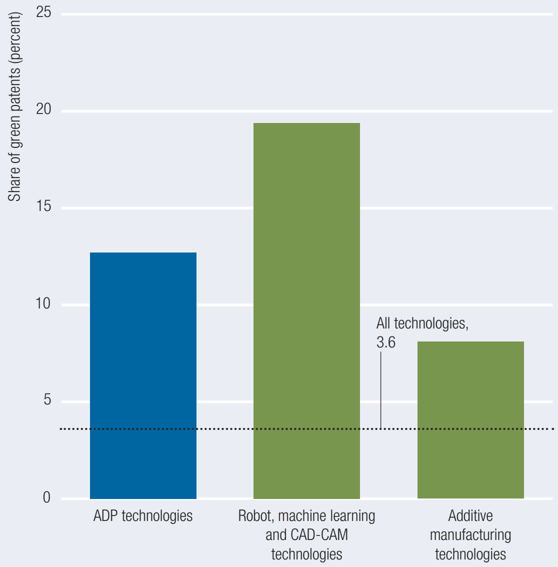
ADP technologies have above-average green content (Figure 15). This is especially the case for the technologies related to robots, machine learning and CAD-CAM systems and, to less extent, for additive manufacturing technologies. The most important characteristic highlighted by patent reviewers of these technologies is their potential contribution to mitigating greenhouse gas emissions. This is another important dividend to consider, especially in relation to the ISID framework (see Figure 1).

ADP technologies boost circular economy processes

ADP technologies are also expected to boost circular economy processes, decoupling natural resource use from the environmental impact of economic growth. This, in turn, supports the achievement of the SDG 6 for energy, SDG 12 for sustainable consumption and production and SDG 13 for climate change. In circular economy processes, resource flows—particularly materials and energy—are narrowed and, to the extent possible, closed. Products are designed to be durable,

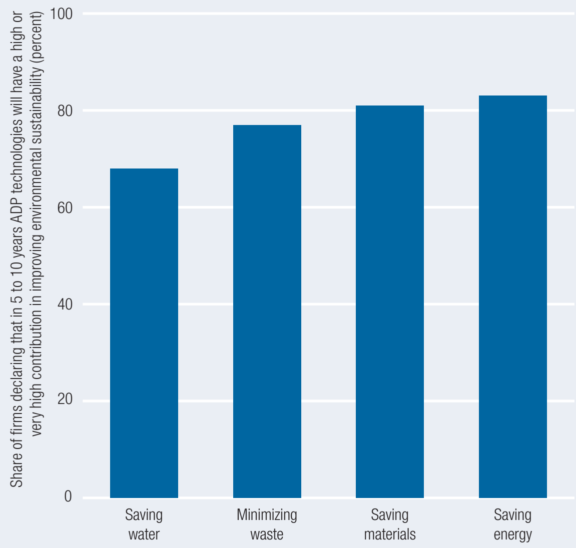
> **The use of ADP technologies would lead to environmental improvements**

Figure 15
ADP technologies have above-average green content



Note: When a patent examiner considers that a patent is contributing to climate change mitigation, a special Y02 tag is attached. This tag makes it possible to identify from all patents the subgroup that refers to green technologies and compare with it the corresponding share of green patents in all patents applied in any technology field (not only ADP technologies) in the past 20 years. CAD-CAM is computer-aided design and computer-aided manufacturing.
Source: UNIDO elaboration based on dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018).

Figure 16
The majority of firms engaging or ready to engage with ADP technologies agree that these will lead to environmental improvements



Note: Data refers to firms surveyed in Ghana, Thailand and Viet Nam and includes only those firms currently engaging or ready to engage with ADP technologies.
Source: UNIDO elaboration based on data collected by the UNIDO firm-level survey "Adoption of digital production technologies by industrial firms" and Kupfer et al. (2019).

reusable and recyclable, and materials for new products come from old products. Circular economy models also reduce the underuse of products and provide resource efficiency benefits. Data from electronic devices, networks and internet-connected equipment can provide companies with insights about how they use their resources and how they could improve the design of their products and services, product life-cycle management or supply chain planning (Rizos et al. 2018).

Technologically dynamic firms are optimistic about environmental improvements

Firm level data confirm this pattern. In Ghana, Thailand and Viet Nam, in all environmental domains—water, energy, materials and waste—the majority of firms already engaging or ready to engage with ADP technologies agree that the use of these technologies would lead to environmental improvements (Figure 16). Efficient use of materials means sustainability, but also savings that can trigger further expenditures and multiplier effects for firms and generate rebound effects increasing economic activity and thus environmental impact.

The dividends are not automatic and entail risks

Developing country firms face supply-chain reorganization and backshoring

An important area of concern regarding ADP technologies is their potential impact on the organization of global production. For firms in developing countries —especially those participating in GVCs—threats from supply chain reorganization, delocalization of production and backshoring are a common fear.

Digitalization could increase oligopoly and power concentration

Firms in developing countries may be harmed by the progressive integration of ADP technologies into GVCs,

“ADP technologies might induce backshoring, even though it is not frequent

since they might face increasing barriers to access. As the increased digital integration of systems through software platforms affects the structure of GVCs, concerns arise about the coordination and governance mechanisms in fully digitalized supply chains and possibly increasing concentration of power and oligopolistic and monopolistic markets (Andreoni and Anzolin 2019).

Advanced country backshoring could make developing country cheap labour irrelevant

Firms in developing countries may also be harmed by the progressive diffusion of ADP technologies in advanced economies. The adoption of these technologies is expected to reduce the relevance of cheap labour as a comparative advantage and increased backshoring towards industrialized economies, taking away some manufacturing activities and reducing job creation (Rodrik 2018). New cheap capital machinery and robots replacing manual work could induce companies to return production to high-income countries close to big consumer markets. This phenomenon could counterbalance previous decades' extension of GVCs to decentralize production from high-income countries to lower-income countries for activities requiring low skills and low salaries, such as assembly.

Not much backshoring is evident

Beyond hypotheses and anecdotal examples, however, general evidence of backshoring is still scarce, so drawing conclusions on the ultimate impact on developing country employment and designing sound policies to address it is difficult. Empirical work for this report using the 2015 European Manufacturing Survey data of firms from eight European countries (Austria, Croatia, Germany, the Netherlands, Serbia, Slovenia, Spain and Switzerland) analysed the extent and determinants of backshoring.[5] Three clear findings emerge.

- First, backshoring is not as widespread as perceived in the media and in the policy debate: 5.9 percent of all firms have backshored, while 16.9 percent have offshored.
- Second, labour cost is not the main reason why firms backshore from emerging economies, but it is important in backshoring from other high-income countries. Flexibility in logistics appears to be the main reason for backshoring from emerging economies. This finding is surprising, since in the current debate, the fear of job displacement due to advanced technologies relates to introducing cheap machines or robots that can replace human labour by further reducing production costs.
- Third, backshoring is more frequent for some sectors (chemical industry, machinery, electrical industry or transport equipment—rather than low-technology sectors) and for firms more intensively adopting ADP technologies. So, ADP technologies might induce backshoring, even though it is not frequent.

Gender differences are pronounced in the susceptibility of jobs to digitalization

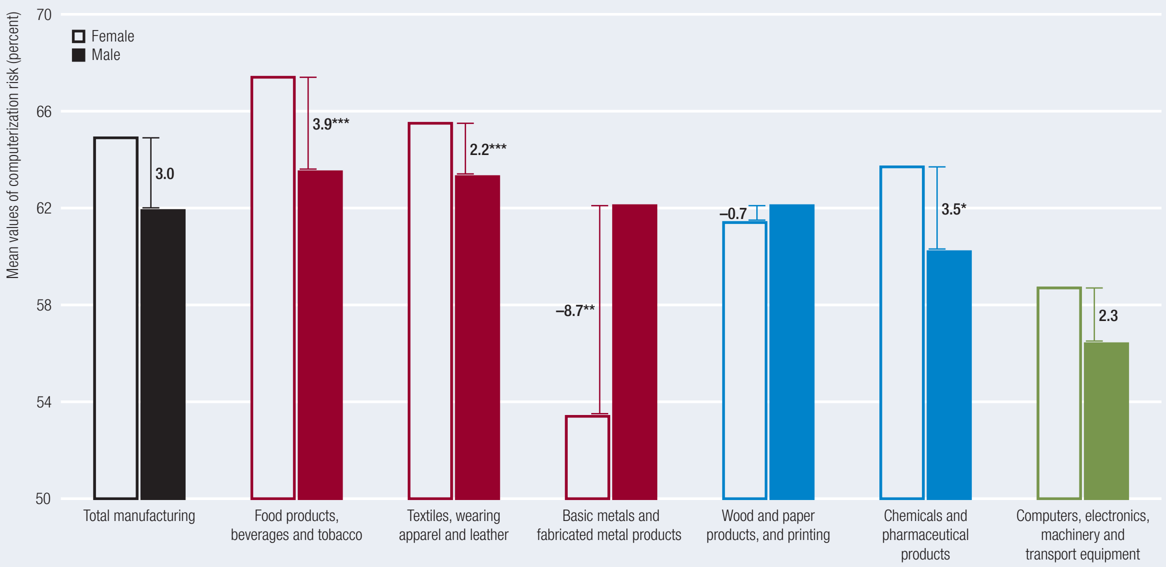
Yet another area of concern is gender inequalities. Extended adoption of ADP technologies might increase the gap between men and women in manufacturing labour markets, especially in developing countries. Female workers in manufacturing are found to be more exposed to the risk of computerization than men are, since the computerization risk they face is on average about 2.9 percent higher than that of their male colleagues (Figure 17). Considering the type of occupation currently preformed, women are more likely to face a higher computerization risk than men if they are employed in food, beverages and tobacco, textiles and leather and chemicals. Interestingly no statistically significant gender differences in computerization risk are observed in the computers, electronics and vehicles sector.

Why do women tend to face a higher risk of losing jobs due to automation?

The gender differences in computerization risk can be explained by, among other reasons, differences in skill endowments. Women in manufacturing on average score significantly lower than male workers in all skills that are particularly valuable to operate with ADP technologies and that constitute the broad category

"There are no one-size-fits-all solutions

Figure 17
Female workers are more likely to face a higher computerization risk than men if they are employed in food, textiles and chemicals



Note: Computerization risk refers to the probability that an occupation will be computerized in the near future. The figure shows the female–male differences in mean values of computerization risk by sector. t-test of differences in means: *** $p < 0.000$; ** $p < 0.05$; * $p < 0.1$. The analysis includes Armenia, Colombia, Georgia, Ghana, Kenya, Lao People's Democratic Republic, North Macedonia, the Plurinational State of Bolivia, Sri Lanka, Ukraine and Viet Nam. The colours of the bars reflect the technology and digital intensity classification of industries. Green = TDI industries (industries that are simultaneously intensive on digitalization and technology). Blue = industries that are intensive on either digitalization or technology but not on both. Red = industries that are intensive on neither digitalization nor technology.
Source: UNIDO elaboration based on dataset by Sorgner (2019) derived from the STEP Skills Measurement Program (World Bank 2016).

"skills of the future." These skills are supposed to thrive in the 4IR and protect workers from destructive digitalization because they are less likely to be replaced by new technologies but, instead, more likely to be complemented by them. Gender gaps are significantly negative in all the "skills of the future." As a more positive note for female workers, gender gaps in soft skills are less pronounced. Since recent empirical evidence supports the argument social skills are increasingly important, an advantage in these skills can contribute to narrowing gender gaps in the future.

Increasing women's equitable participation promotes inclusive and sustainable industrial development

UNIDO recognizes the importance of a comprehensive debate on the relationship between gender and ADP technologies in manufacturing. Increasing women's equitable participation in the industrial workforce and the development of technologies is necessary to promote inclusive and sustainable industrial development (UNIDO 2019b).

What policy responses can make ADP technologies work for ISID?

Responses are highly contextual

Strategic responses to ADP technologies are mixed across and within countries; they are highly contextual, reflecting the extent of industrialization, the penetration of digital infrastructure, the accumulation of technological and productive capabilities, the tradition of intervention in economic matters of national governments, and national priorities and capacities to mobilize public-private partnerships. There are no one-size-fits-all solutions, and it is still difficult to identify ready-made models. Generally, responses remain at the trial stage, with distinct degrees of articulation in long-term national development strategies.

And depend on the relative position of economies

Responses also depend on the relative position of economies: frontrunners, followers and latecomers have different goals and face different challenges. Frontrunners

> **Adoption of ADP technologies requires important efforts in developing framework conditions**

are already at the frontier when it comes to ADP technologies. Their policy responses are oriented towards sustaining or regaining industrial leadership, and combine economic, social and environmental goals. For follower economies, the main aspiration is to close the technology gap with the frontrunners. This implies fostering innovation-driven development, building on the technological and industrial base that is already in place. Many of these economies host advanced manufacturing–ready firms and are even competing in economic activities traditionally reserved for highly industrialized countries. A key challenge is to disseminate throughout the rest of the economy the capabilities already in place in the most advanced part of the manufacturing sector (Rodrik 2018). For latecomers and laggards, what's most important is to set up the basic conditions of infrastructure and capabilities to get ready to absorb the new technologies.

Some general areas for policy action need special attention

Although responses are highly contextual, three areas are very important

Enhancing readiness to adopt and exploit the new technologies requires action on three fronts: developing framework conditions, fostering demand and leveraging ongoing initiatives, and strengthening skills and research capabilities (Table 3).

Framework conditions include the institutionalization of multistakeholder approaches to industrial policy formulation

Adoption of ADP technologies requires important efforts in developing framework conditions related to regulations and digital infrastructure, the institutional setting for policy formulation and the channels for international collaboration and technology transfer. The institutional setting is particularly important to make ADP technologies work for ISID. New industrial policy formulation, in this context, should stem from close collaboration between private and public sectors, in which learning (identifying constrains), experimentation (finding ways of removing these constraints), coordination (placing all relevant stakeholders in the table) and monitoring (assessing the results) should be key guiding principles (Rodrik 2007, 2018).

Fostering demand requires awareness and funding

Even if the framework conditions are in place, countries need to foster the demand and adoption of the new technologies. This requires concentrated efforts

Table 3
Areas of policy action to make ADP technologies work for ISID

Broad area	Issue to be tackled	Specific actions	Country examples
Developing framework conditions	Regulations and digital infrastructure	*Update and develop regulatory reforms to facilitate a digital economy*	• In 2018, **Mauritius** launched a comprehensive policy framework, Digital Mauritius 2030, to boost economic development. Specific areas of intervention include ICT governance, talent management, a national broadband strategy and stronger protection of intellectual property rights and data, data privacy and cyber-security. • Over the past 15 years, **Viet Nam** has enacted a complex governance reform to support the emergence of smart manufacturing. This includes policies, master plans and laws around e-commerce, e-transactions, cyber-security, information technologies, intellectual property, investment in digital infrastructure and introduction of advanced technologies in production and business.
		Investment in ICT and broadband infrastructure to foster access to high-speed internet	• In 2016, **Chile** announced the Strategic Programme Smart Industries 2015–2025 to upgrade ICT infrastructure, to increase speed in national broadband and expand penetration of high-speed internet in the country. • The national strategy **Thailand 4.0,** contained in the country's 20-Year National Strategy (2017–2036) promotes institutional reforms to improve framework conditions, including incentives (corporate tax reductions and R&D subsidies), investments in high-speed internet infrastructure and the establishment of digital parks and development zones.

Countries need to foster demand and adoption of new technologies

Table 3 *(continued)*
Areas of policy action to make ADP technologies work for ISID

Broad area	Issue to be tackled	Specific actions	Country examples
Developing framework conditions	Institutional infrastructure and private sector role	*Institutionalize multistakeholder and participatory approaches to industrial policy formulation, including public–private dialogue and shared leadership between different ministries*	• In **Brazil,** the development of the Science and Technology and Innovation Plan for Advanced Manufacturing involved a triple-helix approach (government, private entities and education and research organizations). The Ministry of Science, Technology, Innovation and Communications and the Ministry of Industry, International Trade and Services lead from the government side. Significant knowledge came from a task force consulting private organizations about their perspectives on the challenges and opportunities stemming from smart manufacturing across different Brazilian industries and regions. • In **Mexico,** the national strategy Roadmap 2030 built on a collaboration among the Ministry of Economy, ProSoft 3.0 (an official programme to promote the domestic software industry), the Mexican Association of Information Technologies and other private sector organizations. • In **South Africa,** the Department of Telecommunications and Postal Services, the Department of Science and Technology and the Department of Trade and Industry led an integrated strategy, in consultation with industry, labour and civil society. In addition, a Presidential Commission on the 4IR was established in 2019 to coordinate work across all involved governmental institutions.
	International collaboration and technology transfer	*Facilitate connections with international initiatives around the adoption of ADP technologies*	• In 2015, **China** and **Germany** agreed to promote readiness of their respective economies for ADP technologies in a memorandum of understanding linking Made in China 2025 and Industrie 4.0. The proposed activities consider the promotion of networks of Chinese and German enterprises in smart manufacturing. Collaboration is already bearing fruit through a Sino-German Industrial Park jointly established as a platform to connect Chinese enterprises and German technology. • In 2018, Nuevo León, **Mexico** signed a two-year memorandum of understanding with the Basque Country, **Spain,** to underpin collaboration between their respective ADP technology strategies. The government of Nuevo León recently launched the programme MIND4.0 Monterrey 2019, a start-up accelerator that emulates a similar pilot initiative in the Basque Country (BIND 4.0) matching local manufacturing firms with domestic and foreign innovators and entrepreneurs.
		Establish partnerships with foreign organization and MNCs or consulting firms	• **Kazakhstan's** new digitalization strategy, Digital Kazakhstan, benefited from collaboration of Germany's Fraunhofer Institute with the Kazakhstan Ministry of Industry and Infrastructure Development. Activities included a diagnostic study on about 600 domestic companies' readiness to adopt ADP technologies. Firm with semiautomated production will be supported to progressively transform into digital factories. Pilot companies started implementation in October 2018.
Fostering demand and adoption	Access and affordability of ADP technologies	*Develop innovative funding mechanisms and support instruments or expand public funding for ecosystem enablers*	• The government of **South Africa** proposed a Sovereign Innovation Fund to fund high-technology projects on smart manufacturing–related areas. The government pledged a seed investment of 1–1.5 billion rand (around $111 million) for 2019/2020. The fund is part of a strategy to support domestic firms to benefit from technology transfer. • In 2017, the government of Zhejiang Province, **China**, launched the Plan for Enterprises Deploying the Cloud, an initiative to promote adoption of and innovation in cloud technologies, particularly among small and medium-sized enterprises. The initiative combines funding through voucher schemes to lower the cost of cloud technology with a complex approach to foster capabilities. As part of the programme more than 1,100 seminars on cloud computing have been organized, covering more than 90,000 industrial firms and 100,000 participants.

to raise the awareness of firms on the potential use and benefits of these technologies together with the facilitation of funding for their adoption. Targeted support should also be addressed to actors (for instance, small and medium-sized enterprises, SMEs) that are lagging from a technological perspective.

“Governments can support the strengthening of capabilities through dedicated learning centres

Table 3 *(continued)*
Areas of policy action to make ADP technologies work for ISID

Broad area	Issue to be tackled	Specific actions	Country examples
Fostering demand and adoption	Awareness regarding use and benefits of ADP technologies	*Develop awareness centres and organize international summits, conferences and workshops to expand firms' knowledge of ADP technologies*	• In 2017, the government of **India** opened four new centres for promoting ADP technologies in Bangalore, New Delhi and Pune. While independent, the centres fall under the purview of the Ministry of Industry, Department of Heavy Industry. Their mandate is to support the implementation of Make-in-India, particularly by enhancing manufacturing competitiveness through a better understanding and broader adoption of ADP technologies by manufacturing small and medium-sized enterprises. • Since 2015, the government of **Viet Nam** has organized annual summits or international gatherings to raise awareness, explore and possibly tighten public–private collaboration or demonstrate technologies and solutions available for domestic agents interested in ADP technologies.
	Readiness of vulnerable actors, such as small and medium-sized enterprises	*Provide targeted support to actors that are technologically lagging behind*	• In **Spain,** the government of the Basque country launched Basque Industry 4.0, which includes pilot activities to assist domestic SMEs in accessing training on ADP technologies associated with manufacturing, and spaces designed for self-diagnosis and fine-tuning for advanced manufacturing. • In 2019, the government of **Malaysia** launched Industry4WRD Readiness Assessment, a programme under the national strategy Industry4WRD that helps to determine small and medium-sized enterprises' readiness to adopt ADP technologies.
Strengthening capabilities	Development of human resources	*Enhance international collaboration around skill development and employability*	• In **Colombia,** universities in Valle del Cauca recently agreed to collaborate with the Association of Electronic and Information Technologies (GAIA) of the Basque country. The parties expect to foster digital culture and entrepreneurship among students in Valle del Cauca.
		Offer/facilitate direct experience and exposure and learning from the new technologies, including new approaches to technical and vocational education and training (TVET)	• The government of **Uruguay,** in collaboration with UNIDO and the German industrial control and automation company Festo, has established the Centre of Industrial Automation and Mechatronics (CAIME), a public technology centre to upgrade technical skills and encourage domestic firms to adopt smart manufacturing processes. • In **Malaysia,** the Ministry of Human Resources offers a National Dual Training Scheme, inspired by the German Dual Vocational Training Programme, aimed at equipping workers to use ADP technologies.
	Development of research capabilities	*Expand the scope and number of research institutions*	• In **Chile,** the Office of Economy of the Future launched the project Astrodata, whose objective is to capitalize on the processing potential of astronomical big data and cloud computing, not only for scientific applications and human capital development but also for economic purposes. • In **Kazakhstan,** the Ministry of Education and Science will mobilize research capacities at the Industrial Automation Institute (based in the Kazakh National Research Technical University) to carry out applied research and technology transfer connected with technological problems faced by business seeking to use ADP technologies.

Source: UNIDO elaboration.

Capabilities build on new skills and research

Ultimately, for firms to be able to adopt the new technologies, the required capabilities in terms of skills and research should be in place. Governments can support the creation and strengthening of these capabilities through dedicated learning centres and new approaches to technical and vocational education and trainings that are aligned with the emerging requirements of firms. Expanding the scope and number of research institutions which are specifically dealing with ADP technologies is also key for the absorption of these technologies and their adaptation to the local environment.

> **“Without international support, low-income countries run the risk of being stymied even more**

A call for further international collaboration

New windows of opportunity will depend on individual responses and readiness

How much will ongoing breakthroughs in ADP technologies open new windows of opportunity to leapfrog, or to avoid falling farther behind? The extent will depend on individual responses and readiness through active industrial policy, digital literacy, skills and education—and not just wage rates, domestic markets and positions in global value chains (Lee et al. 2019, Mayer 2018).

Remember that it takes commitments and substantial resources to develop capabilities

Policy-makers, particularly in developing countries, should remember that it takes commitments and substantial resources to develop the capabilities required to take up new technologies and assimilate any associated productive transformations (Lee 2019, Steinmueller 2001). Taking small but well-informed steps to test technological and policy options, according to the desired goals, is recommended before committing fully to implementation. There is much room for further research and policy experimentation to learn and exchange policy lessons through enhanced international collaboration.

The international community should support lagging economies

The results in the report indicate that large parts of the world, mostly LDCs and other low-income countries, are still far from engaging with the new technologies. This calls for immediate action from the international community to support developing countries—especially LDCs—in adopting the ongoing technological breakthroughs. Without international support, low-income countries run the risk of being stymied even more, lagging farther behind and failing to achieve several (if not all) the SDGs. As discussed above, this support should be oriented towards building basic, intermediate and advanced industrial and technological capabilities, together with digital infrastructure.

There is good scope for further international collaboration

Important benefits can come from close collaboration among countries at different stages of readiness for the adoption of ADP technologies. The potential for expanding such collaboration is significant. In many national strategies of follower economies, some frontrunner economies are identified as a preferred partner to facilitate technology transfer, human resource development and joint implementation of pilot projects, but also to explore joint business models. Partnerships can also be done with other countries at similar levels of adoption of ADP technologies. Knowledge transfers can take place on a more equal footing and be closer to common realities. For the BRICS, such collaboration is already motivating joint research activities and innovation agendas on big data, ICTs and other ADP technologies and their applications, as well as on ICT infrastructure and connectivity (BRICS Information Centre 2017).

Closer collaboration should be the basis of national strategies

Closer collaboration should be the basis of strategies to address developing countries’ diverging views on the challenges that ADP technologies might bring in their path towards inclusive and sustainable industrial development. Many of these questions are not new, but the issues are becoming more pressing because of their possible implications for digital divides. Consensus on the challenges and opportunities is still largely out of reach, and domestic politics are likely to stall major international collaborations. That is why international policy coordination and collaboration should continue to buttress efforts to leap forward, enabling organizations and countries to share knowledge and experiences on how to identify and address the opportunities and challenges stemming from the 4IR—and ensure that no one is left behind.

Notes

1 In this report, global patents are defined as those patents that are simultaneously applied in at least two of the following patent offices: the European Patent Office, the United States Patent and Trademark Office, the Japan Patent Office and the China National Intellectual Property Administration Office.

2 These generations were first proposed by IEL (2018) and then elaborated further in the UNIDO background paper by Kupfer et al. (2019).

3 For full results see the UNIDO background paper prepared by Pietrobelli et al. (2019).

4 The analysis is based on the UNIDO background paper prepared by Ghodsi et al. (2019) and builds on the existing empirical work on the relationship between technological change, employment and industrial growth pioneered by Abeliansky and Prettner (2017), Acemoglu and Restrepo (2018) and Graetz and Michaels (2018).

5 See UNIDO background paper prepared by Dachs and Seric (2019) for the details of the analysis.

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Annex

Table A1
Countries and economies by level of engagement with ADP technologies applied to manufacturing

Frontrunners (10 economies)	Followers (40 economies): As producers (23 economies)	Followers (40 economies): As users (17 economies)	Latecomers (29 economies): As producers (16 economies)	Latecomers (29 economies): As users (13 economies)	Laggards (88 economies)
Economies actively engaging with ADP technologies					
China	Australia	Algeria	Bosnia and Herzegovina	Costa Rica	All other economies that, according to the United Nations Statistical Division, had more than 500,000 inhabitants in 2017
France	Austria	Argentina	Bulgaria	Côte d'Ivoire	
Germany	Belgium	Bangladesh	Chile	Ecuador	
Japan	Brazil	Belarus	Dominican Rep.	Egypt	
Korea (Republic of)	Canada	Colombia	Estonia	El Salvador	
Netherlands	Croatia	Hungary	Greece	Ethiopia	
Switzerland	Czechia	Indonesia	Kyrgyzstan	Malawi	
Taiwan Province of China	Denmark	Iran (Islamic Republic of)	Latvia	Serbia	
United Kingdom	Finland	Malaysia	Moldova (Republic of)	Tunisia	
United States	Hong Kong SAR, China	Mexico	New Zealand	Turkmenistan	
	India	Portugal	Nigeria	Uganda	
	Ireland	Romania	Philippines	Uzbekistan	
	Israel	Saudi Arabia	Slovenia	Zambia	
	Italy	South Africa	Ukraine		
	Lithuania	Thailand	United Arab Emirates		
	Luxembourg	Turkey	Venezuela (Bolivarian Republic of)		
	Norway	Viet Nam			
	Poland				
	Russian Federation				
	Singapore				
	Slovakia				
	Spain				
	Sweden				

Source: UNIDO elaboration based on dataset by Foster-McGregor et al. (2019).

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“New technologies are a double-edged sword for developing nations. They can enable leapfrogging and faster economic catchup. But in the absence of basic capabilities, skills, and institutions, they also raise barriers to convergence by laggards. This data-filled report presents an up-to-date picture of the technology landscape and outlines strategies for making the most out of the opportunities while avoiding the pitfalls.”

Dani Rodrik, Harvard University

“UNIDO reminds the world in this report that industrialization continues to be essential for economic development. It argues that, through increased productivity and the development of new production sectors, the digital technologies offer significant opportunities in terms of improvements in standards of living and environmental sustainability. They also pose great challenges, given the limited diffusion of these technologies in most developing countries. It calls, therefore, for significant efforts to develop the digital infrastructure, build up the essential human skills and strengthen the research capacities of developing countries –all of which are also areas for increased international cooperation.”

José Antonio Ocampo, Central Bank of Colombia and Columbia University

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