Industrial Development Report 2020

Industrializing in the digital age

UNITED NATIONS
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.

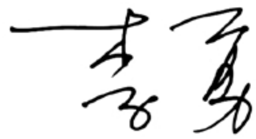
The impact of ADP technologies on developing countries will ultimately depend on their policy responses. There is no "one-size-fits-all" policy strategy to make the new technologies work for inclusive and sustainable industrial development. Our 2020 report provides some strategic policy directions as 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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The Industrial Development Report (IDR) 2020 was prepared under the overall guidance of Li Yong, Director-General of the United Nations Industrial Development Organization (UNIDO). It is the result of two years of intense research efforts, fruitful discussions and close collaboration of an in-house team headed by Cecilia Ugaz, Director for the Department of Policy, Research and Statistics. The team was coordinated by Alejandro Lavopa, who played an instrumental role in the successful completion of the report, and comprised Elisa Calza, Nicola Cantore, Nelson Correa, Smeeta Fokeer, Nobuya Haraguchi, Fernando Santiago Rodríguez and Adnan Seric.

A string of commissioned background papers greatly benefited the drafting of the report, and were submitted by the following experts: Ramiro Albrieu, Caterina Brest López, and Martín Rapetti, Center for the Implementation of Public Policies Promoting Equity and Growth (CIPPEC); Antonio Andreoni, the School of Oriental and African Studies (SOAS) at the University of London; Guendalina Anzolin, University of Urbino; Francesco Bogliacino, National University of Colombia; Cristiano Codagnone, University of Milan and Open University of Catalonia; Bernhard Dachs, Austrian Institute of Technology; Michele Delera, Neil Foster-McGregor, Carlo Pietrobelli, Önder Nomaler, and Bart Verspagen, United Nations University-Maastricht Economic and Social Research Institute on Innovation and Technology (UNU-MERIT); João Carlos Ferraz, David Kupfer, Jorge Nogueira de Paiva Britto and Julia Torracca, Institute of Economics of the Federal University of Rio de Janeiro (IE-UFRJ); Mahdi Ghodsi, Oliver Reiter, Robert Stehrer, and Roman Stöllinger, The Vienna Institute for International Economic Studies (WIIW); Chiharu Ito, Michiko Iizuka, and Izumi Suzuki, National Graduate Institute for Policy Studies (GRIPS); Bart Kemp and Raquel Vázquez, Basque Institute of Competitiveness (Orkestra); Erika Kraemer-Mbula, University of Johannesburg; Keun Lee, Seoul National University; Amaia Martínez and Cristina Oyón, Basque Business Development Agency (SPRI); Mario Pianta, Roma Tre University; and Alina Sorgner, John Cabot University.

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To complement the survey results, the team also collected case studies on manufacturing firms from other developing countries. Profound appreciation is directed to Ciyong Zou and the UNIDO staff from the field offices who have made the data collection process possible, namely: Manuel Albaladejo, Nadia Aftab, Ralf Bredel, Sooksiri Chamsuk, Stein Hansen, Hanan Hanzaz, Muhammad Hammad Bashir Saeed, Lina Touri, René van Berkel, Rajeev Vijh, and Süleyman Yilmaz. The work was supported by Valeria Cantera, Nurshat Karabashov, Sebastián Pérez, Nidhi Sharma, Hongfei Yue and Azhar Zia-ur-Rehman. We are also thankful to the following institutions which facilitated the collection of data in some of these countries: the Ministry of Industry and Information Technology from China, the Ministry of International Trade and Industry from Malaysia, the Turkish Industry and Business Association (TUSIAD) and the Chamber of Industries of Uruguay (CIU).

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Technical notes and abbreviations

References to dollars ($) are to United States dollars, unless otherwise indicated.

This report classifies countries according to four primary groupings: *industrialized economies, emerging industrial economies, other developing economies,* and *least developed countries.* The three latter groupings are together referred to as *developing and emerging industrial economies.* See Annex C.1 for a complete list of countries and economies by region and industrialization level.

The remaining annexes contain more detailed information about methodology and classifications. Annexes A and B provide further methodological details and tables complementary to those in the text of Parts A and B of the report. Annex C contains detailed information on the classifications of economies and sectors used throughout the report.

In-text values in non-$ currencies are generally followed by a $-approximation, which in all cases is based on the average exchange rate for the relevant year.

Components in tables may not sum precisely to totals shown because of rounding.

1IR	First industrial revolution
2IR	Second industrial revolution
3IR	Third industrial revolution
4IR	Fourth industrial revolution
AI	Artificial intelligence
ADP	Advanced digital production
BRICS	Brazil, Russia, 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 systems
DIY	Do it yourself (movements)
DRI	Digitalization Readiness Index
DPT	Digital Production Technologies
EPO	European Patent Office
FDI	Foreign direct investment
GDP	Gross domestic product
GVC	Global value chain
HS	Harmonized System
ICIO	Inter-Country Input-Output
ICT	Information and communications technology
IDR	Industrial Development Report
ILO	International Labour Organization
IoT	Internet of Things
IPR	Intellectual property rights
ISCED	International Standard Certification of Education
ISID	Inclusive and Sustainable Industrial Development
KIBS	Knowledge-intensive business services
LDC	Least developed countries
M2M	Machine-to-machine
MVA	Manufacturing value added
OECD	Organisation for Economic Co-operation and Development
PPP	Purchasing power parity
RCA	Revealed comparative advantage
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
STEP	Skills Towards Employability and Productivity
TDI	Technology- and digital-intensive
TVET	Technical and vocational education and training
UN	United Nations
UNIDO	United Nations Industrial Development Organization
VA	Value added
WIOD	World Input-Output Database

Glossary

Additive manufacturing: Commonly known as 3D printing, the use of special printers to create three-dimensional physical objects from 3D model data by adding layer upon layer through material extrusion, directed energy deposition, material jetting, binder jetting, sheet lamination, vat polymerization and powder bed fusion. Additive manufacturing is contrasted with subtractive manufacturing methods, which use moulds or rotating milling cutters to remove material from a solid block of material (Eurostat 2017).

Advanced manufacturing: Manufacturing systems in industrial sectors and industrial production characterized by the technology associated with the fourth industrial revolution, such as digital production technologies, nanotechnology, biotechnology and new and improved materials.

Advanced digital production technologies: Technologies that combine hardware (advanced robots and 3D printers), software (big data analytics, cloud computing and artificial intelligence) and connectivity (the Internet of Things). Advanced digital production technologies are the latest evolution of digital technologies applied to production, a core technological domain associated with the fourth industrial revolution. They give rise to smart production—also referred as the smart factory, or Industry 4.0.

Artificial intelligence: The branch of computer science seeking to simulate the human capacity to reason and make decisions. The term usually refers to such artificial intelligence techniques as machine learning, deep learning, neural networks, fuzzy logic, computer vision, natural language processing and self-organizing maps to provide machines and systems with human-like cognitive capabilities, such as learning, adapting, perceiving and solving problems. Artificial intelligence can be defined as making computers intelligent and capable of mimicking and predicting human behaviour and solving problems as well as or better than humans.

Big data: Data characterized by unprecedented volume; frequency or speed of being generated, made available and altered; variety of sources, format and complexity, either unstructured or structured; and granularity (OECD 2017, Eurostat 2017). Such data require new forms of processing to enable their use for enhanced decision-making and process optimization. Big data analytics refers to techniques and technologies that allow voluminous machine-readable data to be generated, stored, accessed, processed and analysed to uncover valuable information—patterns, correlations, trends and preferences—that can help organizations make informed decisions (Schaeffer 2017).

Cloud computing: On-demand network use of a shared pool of configurable computing resources such as networks, servers, storage, applications and services that can be rapidly accessed or released with minimal management effort or service provider interaction. Cloud computing services are used over the internet to access software, computing power, storage capacity and the like, where ubiquitous and convenient services are delivered from the server or the service provider; can be scaled up or down, can be used on demand, and are paid for according to capacity used, or else are prepaid (Eurostat 2017).

Computer-aided design and manufacturing: Use of computer systems (both hardware and software applications) to design and draft technical drawings and models and to provide instructions for and control machine tools and equipment to make prototypes, finished products and whole production runs (Mayer 2018). Computer-aided design systems allow building and viewing a design in three-dimensional space, and they facilitate manufacturing by conveying information on materials, processes, dimensions and tolerances.

Computer-aided design can be used by itself, or it can be integrated with and provide inputs to other computer-aided software such as computer-aided manufacturing, which controls the machine tool that creates or assembles the physical product.

Collaborative robot (cobot): A robot that physically interacts with humans. Designed to learn new tasks, cobots are built with passive compliance features and integrated sensors to adapt to external forces. Cobots are typically safe, cost-effective, easy to use and suitable for small-scale production and reduced production cycles. They are also portable and easy to configure and reconfigure for different tasks.

Competitive Industrial Performance Index: Composite index based on three dimensions—capacity to produce and export manufactured goods, technological deepening and upgrading, and world impact—capturing a country's ability to produce and export manufactures competitively and to transform structurally (UNIDO 2019b).

Cyber-physical system: Networked system with embedded intelligent sensors, processors and actuators, designed to sense and interact with the physical world and support production in real time, guaranteeing performance in applications and allowing machine-to-machine or product-to-machine communication about on how to proceed.

Digital capability gap: Divide between the leading companies in digital capabilities and the rest. Unevenness in the pace of developing new capabilities reinforces firm heterogeneity, with a large number of low-capability and low-performance actors coexisting with more advanced ones.

Digitalization Readiness Index: Synthetic index that combines three dimensions from the surveys conducted for Industrial Development Report 2020: the average generation of digital production technologies currently employed by a firm, the generation the firm expects to use in 5 to 10 years and the level of effort the firm is currently making to reach that expected generation. The higher the generation currently used (or expected to be used) and the higher the level of effort, the higher the value of the index.

Followers: Economies actively engaging in advanced digital production technologies by patenting in the field or trading advanced digital production–related goods, but to less extent than frontrunner economies. The follower group is defined by the average values of patent, export and import activity, once frontrunners are excluded from the sample. It has two subcategories. *Followers in production* have above-average patenting activity in advanced digital production technologies, or else have above-average export market shares in this field and relative specialization in this type of export. *Followers in use* have both above-average import market shares in this field and relative specialization in this type of import.

Fourth industrial revolution: The latest wave of technological breakthroughs. The first industrial revolution, between 1760 and 1840, was triggered by the steam engine and featured the mechanization of simple tasks and the construction of railroads. The second, between the late 19th century and the early 20th century, rose with the advent of electricity, the assembly line and mass production. The third, since the 1960s, was driven by the development of semiconductors and mainframe computing, together with the introduction of personal computers and the internet. The fourth industrial revolution is based on the growing convergence between different emerging technology domains, including digital production technologies, nanotechnology, biotechnology and new and improved materials.

Frontrunners: Economies leading in the production of advanced digital production technologies. The group is defined as the top 10 economies in the number of cumulative global patent family applications in these technologies. Together, they account for 90 percent of global patent families, 69 percent of total exports of goods associated with these technologies and 46 percent of total imports of these goods.

Global value chain: A value chain is the full range of activities that firms and workers do to bring a product from its conception to its end use and beyond, including design, production, marketing, distribution and support to the final consumer. When firms are located in different economies, the value chain is considered global.

Inclusive and sustainable industrial development: Long-term industrialization that drives development. It includes three aspects: creating shared prosperity by offering equal opportunities and an equitable distribution of benefits to all, advancing economic competitiveness, and safeguarding the environment by decoupling the prosperity generated by industrial activities from excessive natural resource use and negative environmental impacts. The Lima Declaration, adopted by UNIDO's Member States on December 2, 2013, set the foundation for this vision.

Internet of Things: The next iteration of the internet, where information and data are no longer predominantly generated and processed by humans (as most data created so far have been) but by interconnected smart objects, embedded in sensors and miniature computers that sense their environment, process data and engage in machine-to-machine communication. Internet of Things relies on interconnections through the internet's network of devices, machinery and objects, each uniquely addressable based on standard communication protocols (UNIDO 2017d).

Knowledge-intensive business services (KIBS): Services and business operations heavily reliant on knowledge. In the analysis conducted in the Industrial Development Report 2020, KIBS are broadly defined as sectors C71RMQ (renting of machinery and equipment), C72ITS (computer and related activities) and C73T74OBZ (R&D and other business activities) from the OECD Inter-Country Input-Output system.

Laggards: Economies showing very little or no engagement with advanced digital production technologies. Laggards are economies that cannot be classified as frontrunners, followers or latecomers.

Latecomers: Economies with some engagement with advanced digital production technologies in patenting such technologies or trading related goods, but less than follower economies. The latecomer group is defined by the average values of patent, export and import activity once frontrunners are excluded from the sample. It has two subcategories. *Latecomers in production* either have at least one patent family in the advanced digital production field but fall below the sample average, or have above-average export market shares in this field or relative specialization in this type of exports. *Latecomers in use* either have above-average import market shares in this field or relative specialization in this type of imports.

Machine-to-machine: Direct communication or data exchange between machines, or between machines and devices or components. Machine-to-machine communication encompasses two types. One is machine-to-machine wireless communication with no human intervention. The other is machine-to-mobile and mobile-to-machine communication between mobile devices and machines. Web-based machine-to-machine communication relies on normalized technologies and standardized protocols/formats. The interconnection of more machines able to communicate is known as *Internet of Things*.

Machine learning: An application of artificial intelligence, machine learning systems use general algorithms to figure out on their own how to map inputs to outputs, typically being fed by very large sample datasets (Brynjolfsson, et al. 2017). These systems can improve their performance on a given task over time by amassing experiences and large volumes of data, such as big data.

New technology: The invention and application of new—not previously developed or used—or significantly improved technology, defined as techniques, tools, goods, methods and processes used to address and solve a technical issue in the accomplishment of a purpose.

Process innovation: Implementation of new or greatly improved production or delivery method, including major change in technique, equipment or software (OECD/Eurostat 2005).

Product innovation: Introduction of goods or services that are new or significantly improved in their characteristics or intended uses (OECD/Eurostat 2005).

Research and development (R&D): Creative work undertaken systematically to increase the stock of knowledge, including knowledge of humanity, culture and society, and to use this stock of knowledge to devise new applications. The term covers basic research, applied research and experimental development (OECD 2002).

Robot: A machine, programmed by a computer, capable of carrying out a series of more or less complex actions automatically. Robots can be industrial robots or service robots. An industrial robot is an automatically controlled, reprogrammable and multipurpose manipulator in three or more axes, either fixed in place or mobile, used in industrial applications such as manufacturing processes (welding, painting and cutting) or handling processes (depositing, assembling, sorting and packing). A service robot is a machine that has a degree of autonomy and operates complex and dynamic interactions and coordination with persons, objects and other devices (when used, for example, for cleaning, surveillance or transportation) (Eurostat 2017).

Smart factory: Plant applying smart manufacturing. Used in general to refer to the growing computerization and automation of manufacturing plants.

Smart manufacturing: The application of *advanced digital production technologies* to manufacturing production. The integration of these technologies includes workers, manufactured products, equipment and machinery along all stages of production in an intelligent system. The system's components interact with and control each other, take decisions and implement actions through digital networks of interconnected equipment and sensors, powered by real-time data analytics, machine learning, machine-to-machine communication and other intelligent algorithms (Chukwuekwe et al. 2016).

Technology- and digital-intensive industries: Industries classified as having medium-high or high levels of technology and digital intensity simultaneously, according to the OECD classifications for technology intensity (OECD 2011) and digital intensity (Calvino et al. 2018). Sectors include computers, electronics, electrical machinery and machinery (International Standard Industrial Classification 26 to 28) and transport equipment (International Standard Industrial Classification 29 and 30).

Value added: A measure of output net of intermediate consumption, which includes the value of materials and supplies used in production, fuels and electricity consumed, the cost of industrial services such as payments for contract and commission work and repair and maintenance, the compensation of employees, the operating surplus and the consumption of fixed capital. Manufacturing valued added (manufacturing net output) is the contribution of the entire manufacturing sector to GDP.

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

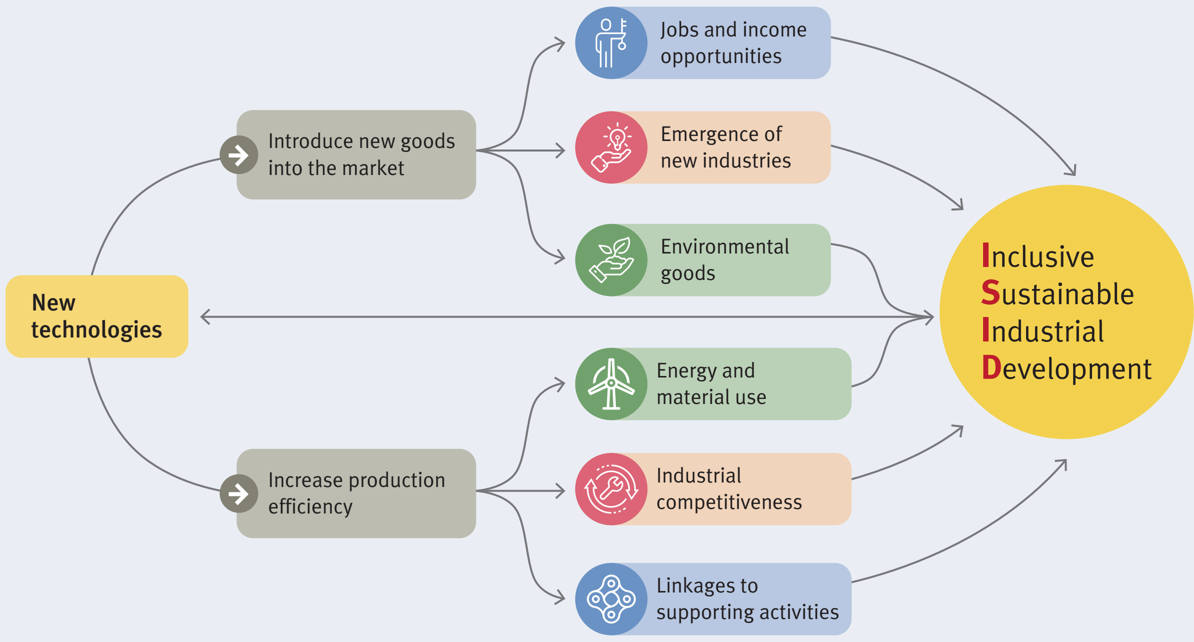
New technologies can lead to product innovations, resulting in the emergence of new industries—and the jobs and incomes associated with them. This supports industrialization and social inclusion. When these innovations are geared to reducing environmental impacts—by introducing *green* manufacturing—they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

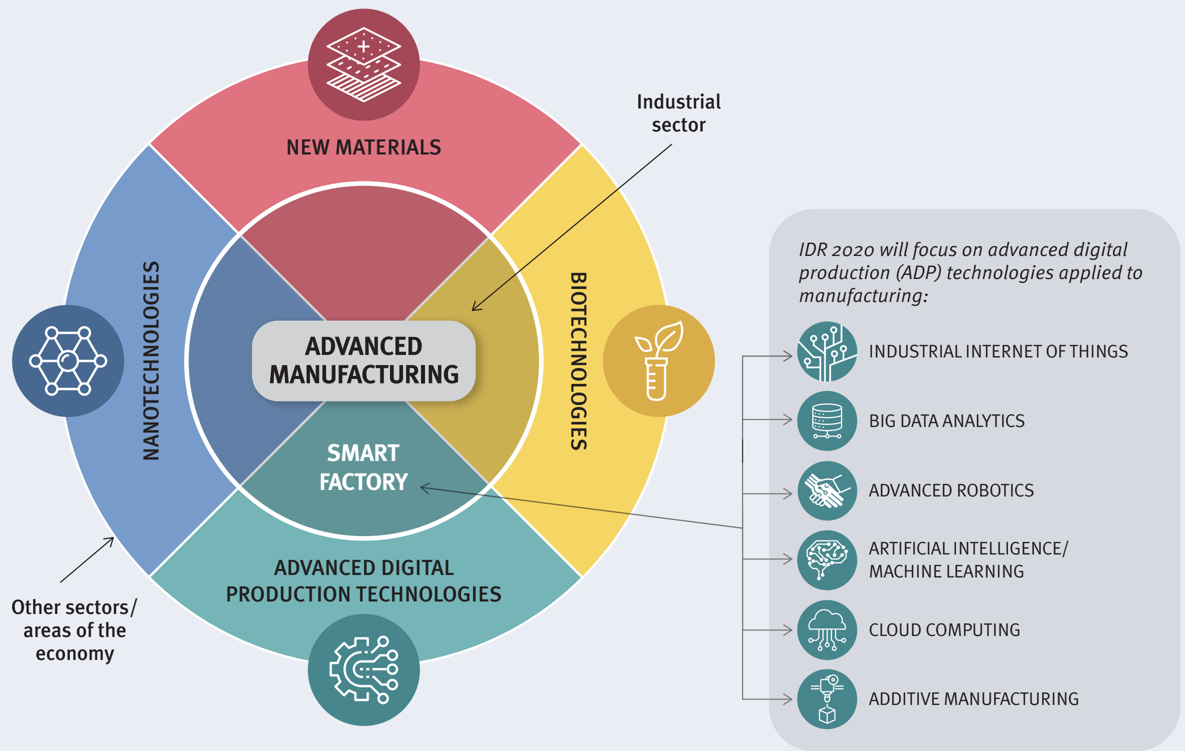
Different waves of technological advancements have pushed economic development since the first industrial revolution (1IR). The invention of the steam engine, the mechanization of simple tasks and the construction of railroads triggered the 1IR between 1760 and 1840. The advent of electricity, the assembly 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 (2017d).

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

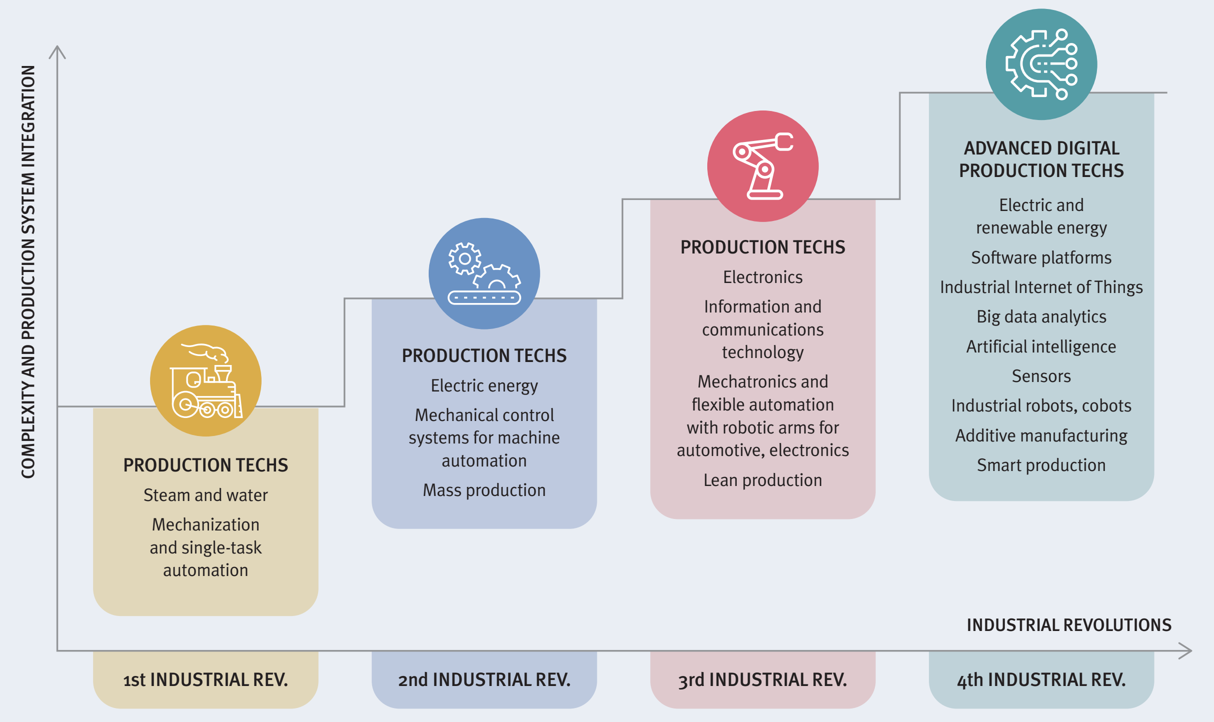
ADP technologies are the last in the evolution of traditional industrial production technologies (Figure 3). In fact, many of these technologies have evolved and emerged from the same engineering and organizational principles of previous revolutions, suggesting an "evolutionary transition" more than 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?

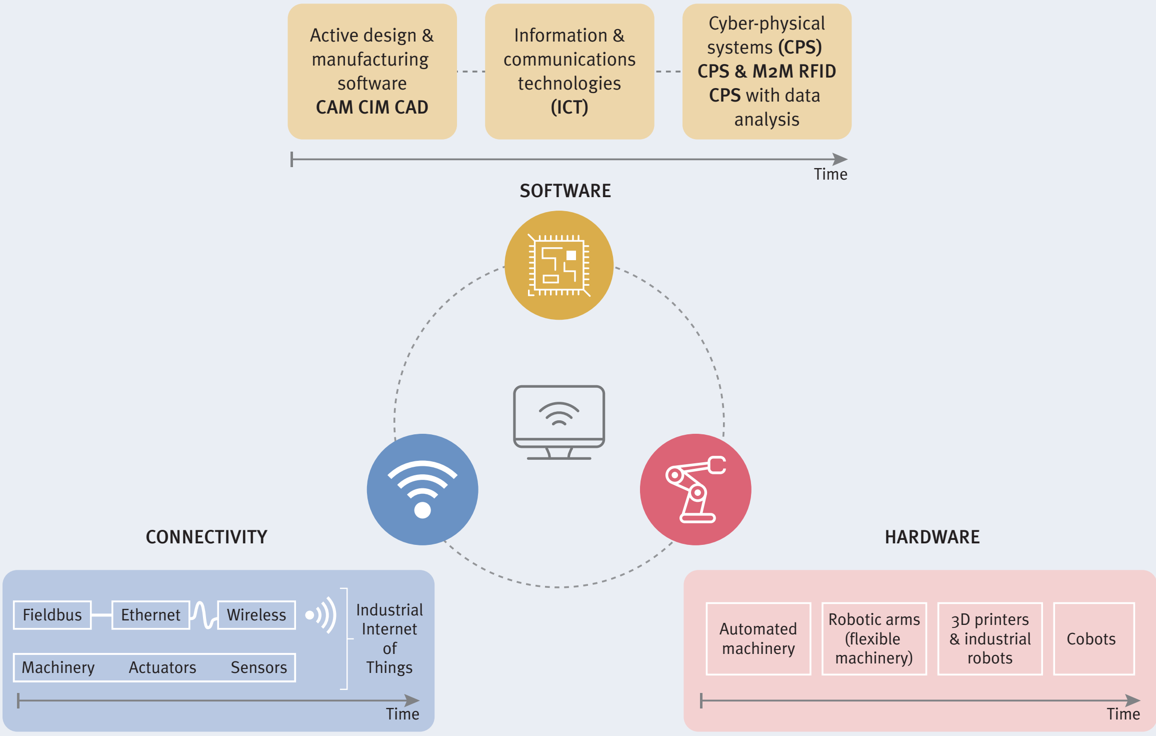
A concentrated global landscape

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)	*Economies actively engaging with ADP technologies*
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	

Note: The characterization is for 167 economies that, according to the United Nations Statistical Division, had more than 500,000 inhabitants in 2017. See Annex A.1 for the classification of economies by their level of engagement with ADP technologies.
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.

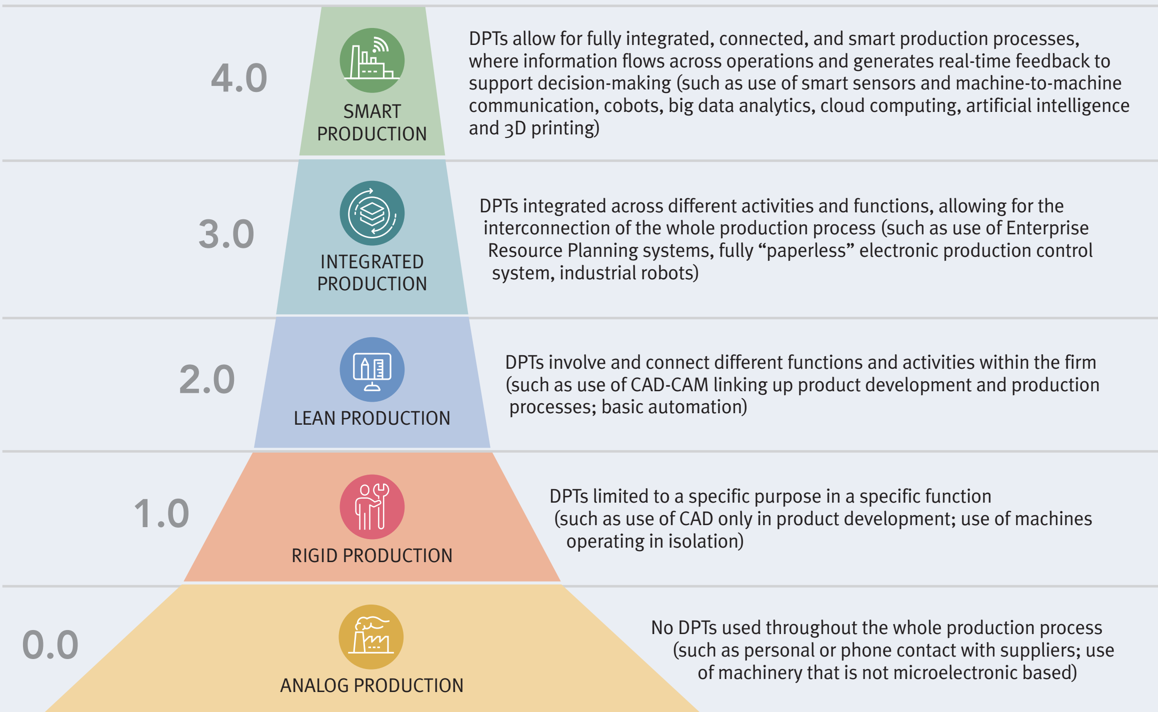
Developing countries retrofit 4IR technologies to incomplete 3IR systems

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.

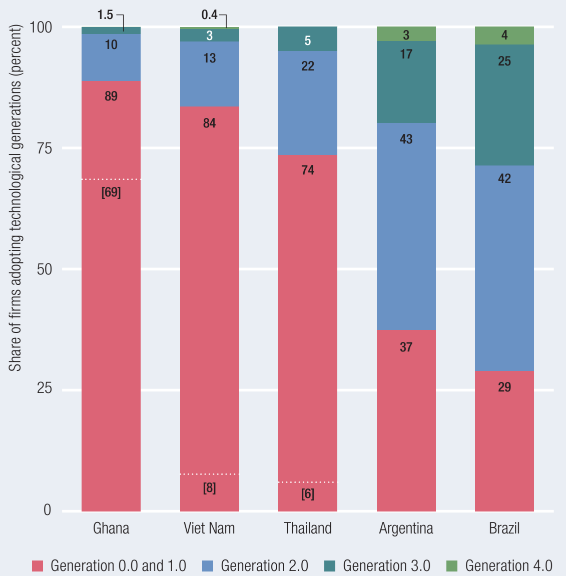
Few firms use the most advanced technologies

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

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. Countries are ordered according to the shares of firms currently adopting the highest generations of digital technologies (generations 3.0 and 4.0). See Annex A.3 for more detailed information on the surveys.
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

directly leapfrog to the most advanced? Differences 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.

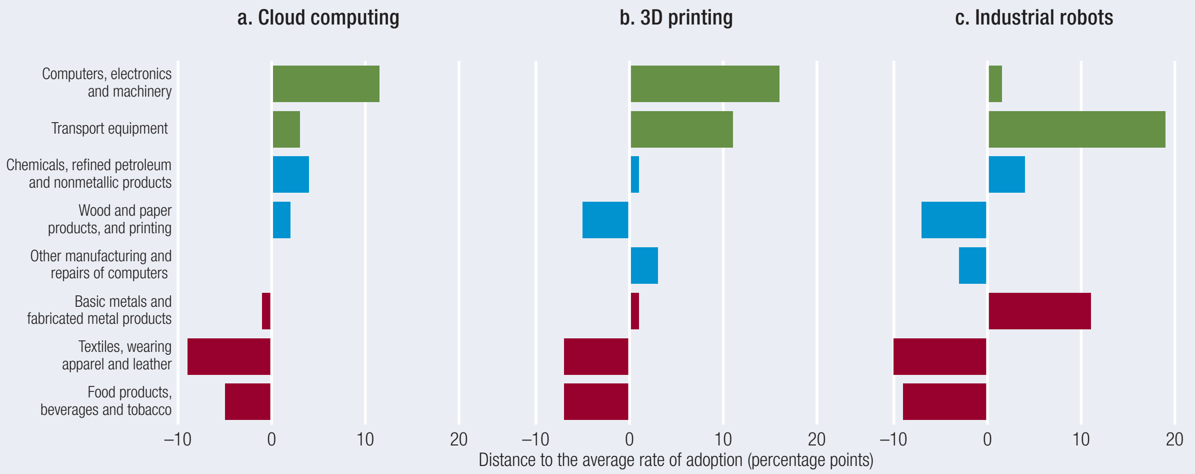
Frontrunners and followers tend to specialize in these industries

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 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

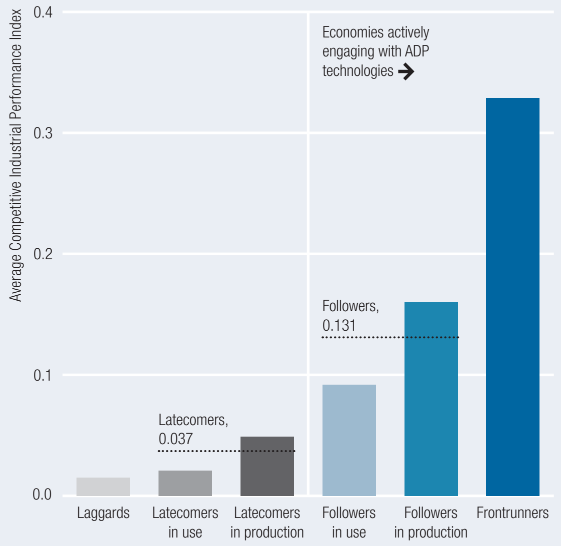
Taken together, these challenges point in one direction —the need to build basic industrial production capabilities as a prerequisite to entering the 4IR. In fact, the differences in engagement with ADP technologies reflect the global heterogeneity of industrial capabilities: frontrunners tend to have 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. ADP is advanced digital production. See Annex A.1 for the classification of economies by their level of engagement with ADP technologies.
Source: UNIDO elaboration based on the Competitive Industrial Performance Index 2019 database (UNIDO 2019c) 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

> 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

the simplest productive activities often require the 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 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

“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).

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

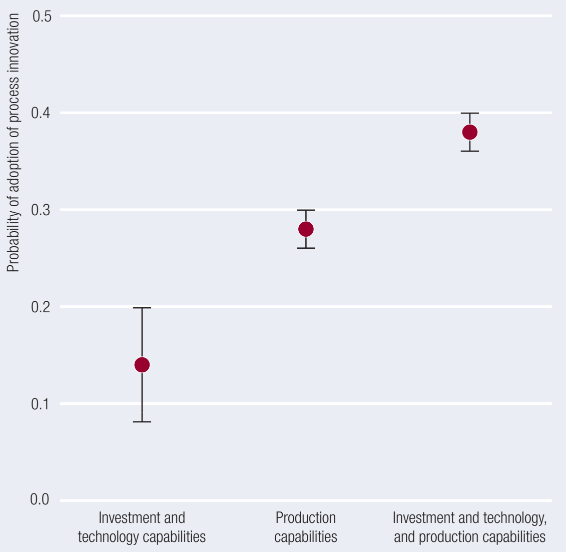
Policy debates tended to focus mostly on investment and technology capabilities. IDR 2020 shows that production capabilities are also of prime importance. An analysis of the determinants of adopting new technologies shows that production capabilities are the most important ones (Figure 9). These capabilities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

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

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).

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 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.

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

What dividends can ADP technologies deliver?

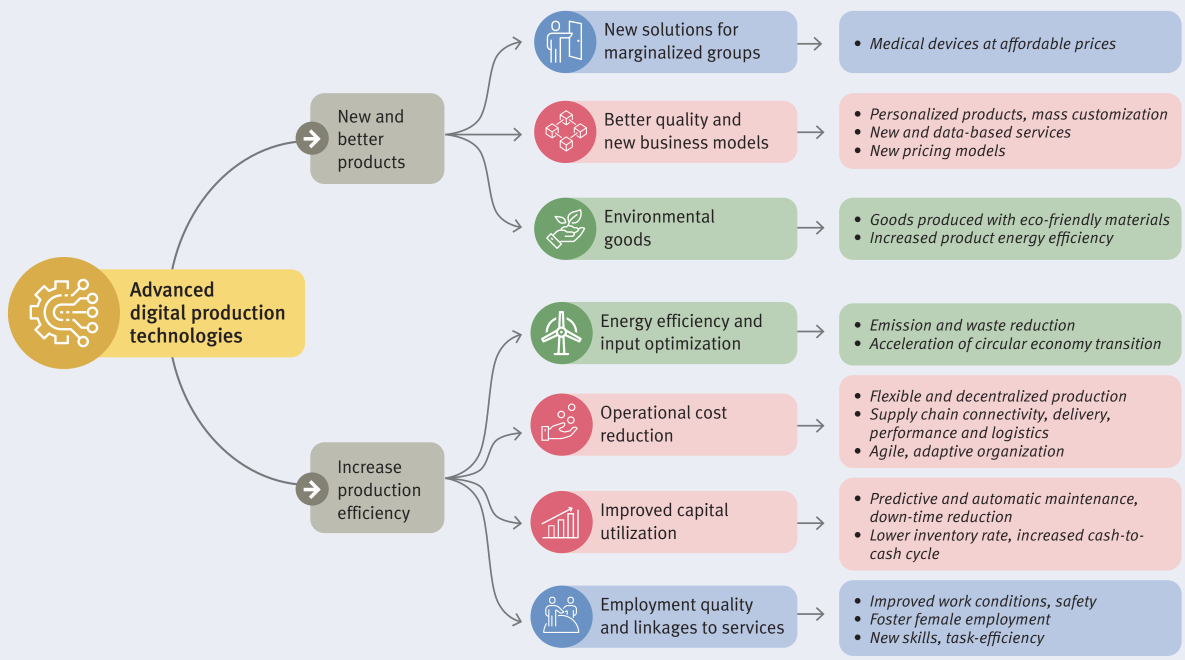
ADP technologies can improve profits, sustain the environment and expand the labour force

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 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

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**

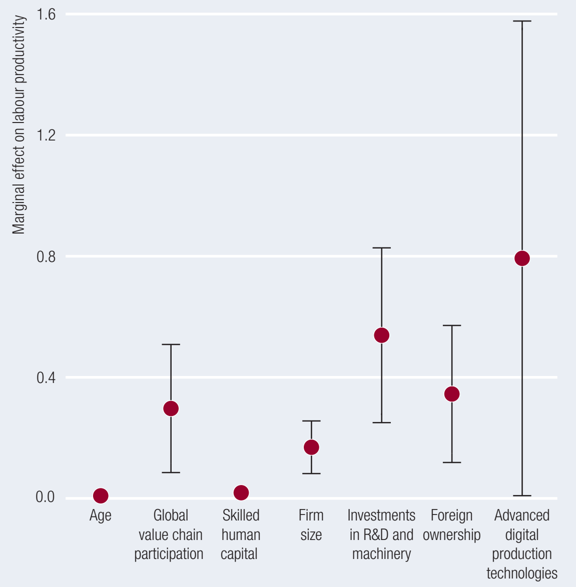
industrialization and boosting economic growth by creating new goods and by blending manufacturing and service activities.

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.

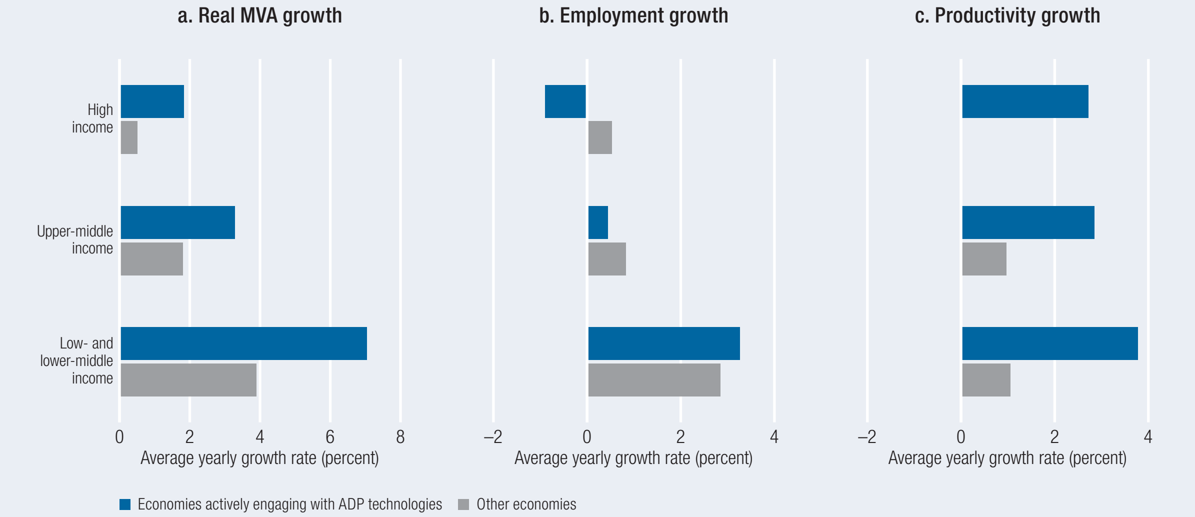
Strengthening intersectoral linkages

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

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: ADP is advanced digital production. MVA is manufacturing value added. 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. See Annex A.1 for the classification of economies by their level of engagement with ADP technologies.
Source: UNIDO elaboration based on the Manufacturing Value Added 2019 database (UNIDO 2019g), ILO (2018), and dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018).

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]

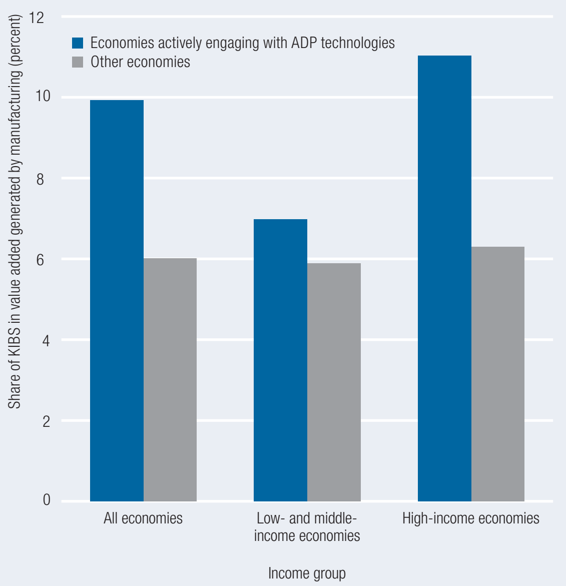
The indirect effects can outweigh the direct effects

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

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

OVERVIEW

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



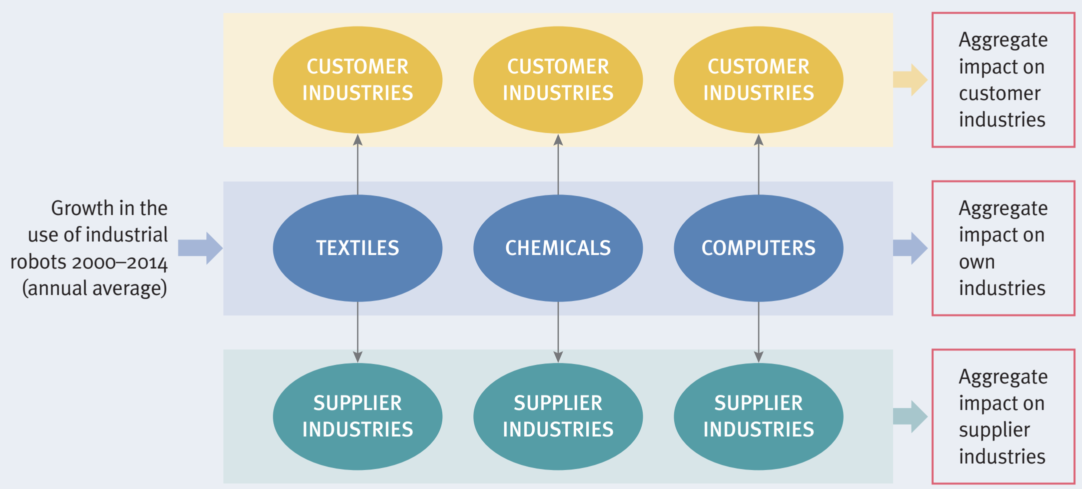
Note: KIBS is knowledge-intensive business services. ADP is advanced digital production. Average values for the period 2005–2015. Manufacturing value added is in current $. The analysis includes 63 economies, which are classified according to World Bank's income group definitions for 2005: 30 low and middle income economies (of which 9 are active), and 33 high income economies (of which 24 are active). See Annex A.1 for the classification of economies by their level of engagement with ADP technologies.
Source: UNIDO elaboration based on Inter-Country Input-Output (ICIO) Tables (OECD 2016, 2018b).

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 employment growth from 2000 to 2014 is positive, though very small. The main positive effects come

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**

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

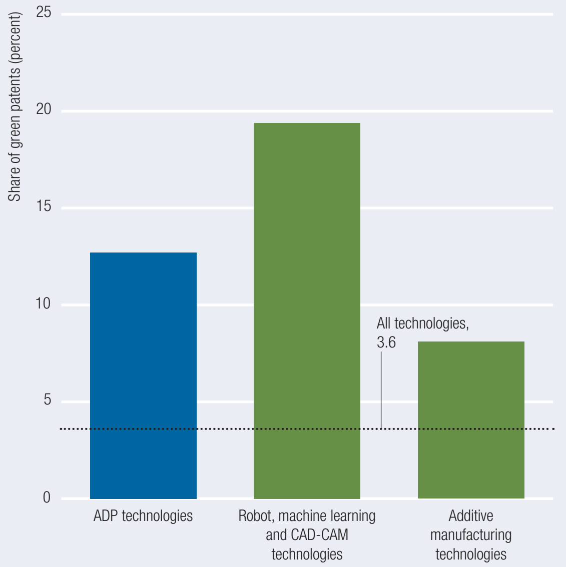
ADP technologies have above-average green content (Figure 15). This is especially the case for the technologies related to robots, machine learning and CAD-CAM systems and, to less extent, for additive manufacturing technologies. The most important characteristic highlighted by patent reviewers of these 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, reusable and recyclable, and materials for new products come from old products. Circular economy models also reduce the underuse of products and provide

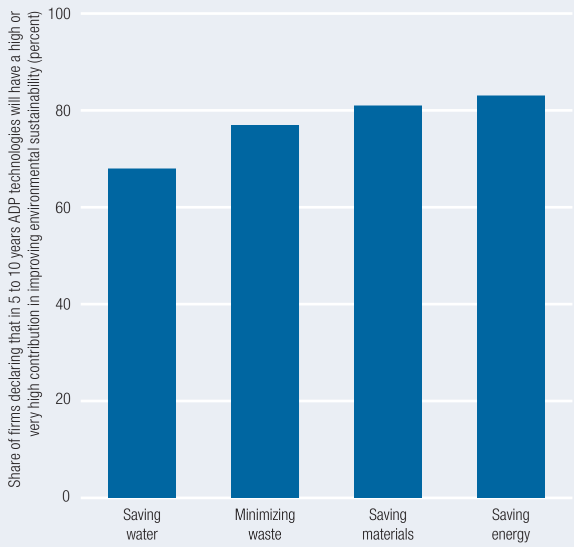
“The use of ADP technologies would lead to environmental improvements

Figure 15
ADP technologies have above-average green content



Note: ADP is advanced digital production. CAD-CAM is computer-aided design and computer-aided manufacturing. 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.
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. See Annex A.3 for more detailed information on the surveys.
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).

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

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

GVCs, 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.

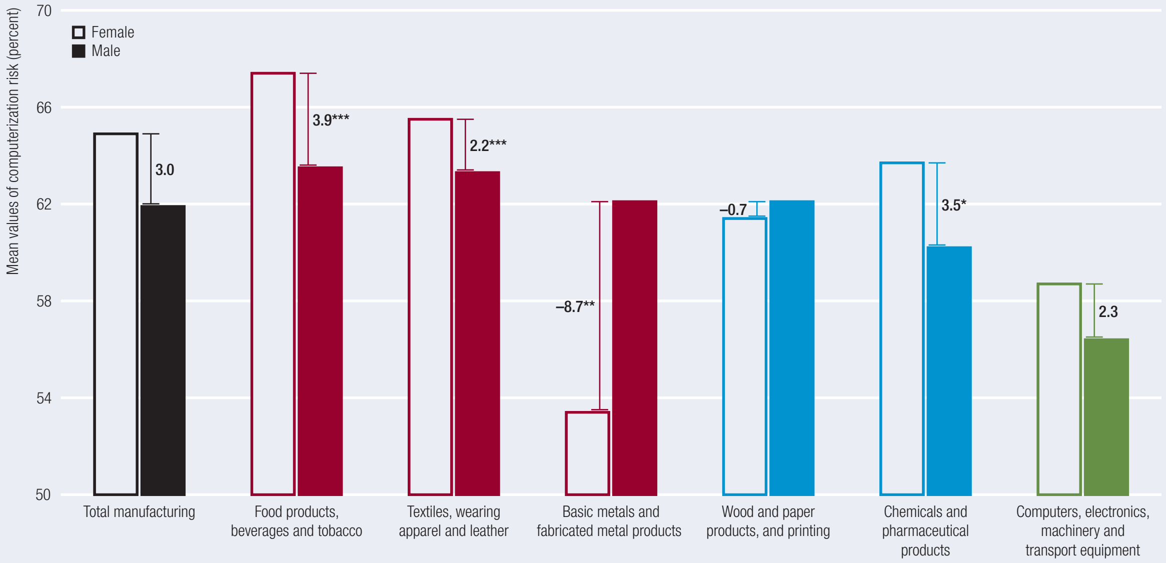
Why do women tend to face a higher risk of losing jobs due to automation?

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

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 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).

in all skills that are particularly valuable to operate with ADP technologies and that constitute the broad category "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 2019d).

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

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

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 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),

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.

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.

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 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.

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

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.

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.

Part A

Industrializing in the digital age

Chapter 1

Advanced digital production technologies and industrial development: A global perspective

The absorption of new technologies is a key driver of successful inclusive and sustainable industrial development (ISID). History shows the links connecting new technologies with the introduction of new goods and processes, the expansion of industries, the creation of job and income opportunities and the advancement of environmental sustainability.

An emerging wave of breakthroughs in digital production technologies—artificial intelligence, big data analytics, cloud computing, Internet of Things (IoT), advanced robotics and additive manufacturing, among others—is transforming manufacturing production. In particular, the convergence of automation and advanced digital technologies is expected to lead to the full development of cyber-physical systems (CPSs; the fusion of the real world with the virtual) and the rise of smart manufacturing production. Under the right conditions, the adoption of these advanced digital production (ADP) technologies by developing countries can foster ISID and the achievement of the Sustainable Development Goals (SDGs).

But the creation and diffusion of ADP technologies remain concentrated globally, although some emerging economies are taking tentative steps towards adopting these technologies. Building on trade and patent data, this chapter presents a global characterization of countries' degree of engagement with ADP technologies. In this characterization, 10 countries—the frontrunners—account for 90 percent of global patents and 70 percent of exports directly associated with these technologies. Another 40 countries—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).

ADP technologies open opportunities for catching up, but exploiting them requires a minimum base of industrial capabilities. A clear positive relationship exists between the roles of different countries as frontrunners, followers, latecomers and laggards in creating and using these technologies and the countries' average set of industrial capabilities. Greater engagement with ADP technologies is associated with higher rates of growth in manufacturing value added (MVA), driven mainly by faster productivity gains. Contrary to common belief, economies actively engaging with ADP technologies also reveal positive employment growth.

This chapter presents the overall conceptual framework (Figure 1.1) and technology focus and describes the creation and diffusion of ADP technologies. It considers the challenges and opportunities that the new technologies can bring for developing countries on their way towards industrial development. Building on the concepts in this chapter, Chapters 2–4 provide a more focused discussion, looking into the impact of ADP technologies on countries (Chapter 2), firms (Chapter 3) and policies (Chapter 4).

Linking industrialization to new technologies: Basic concepts

New technologies and ISID

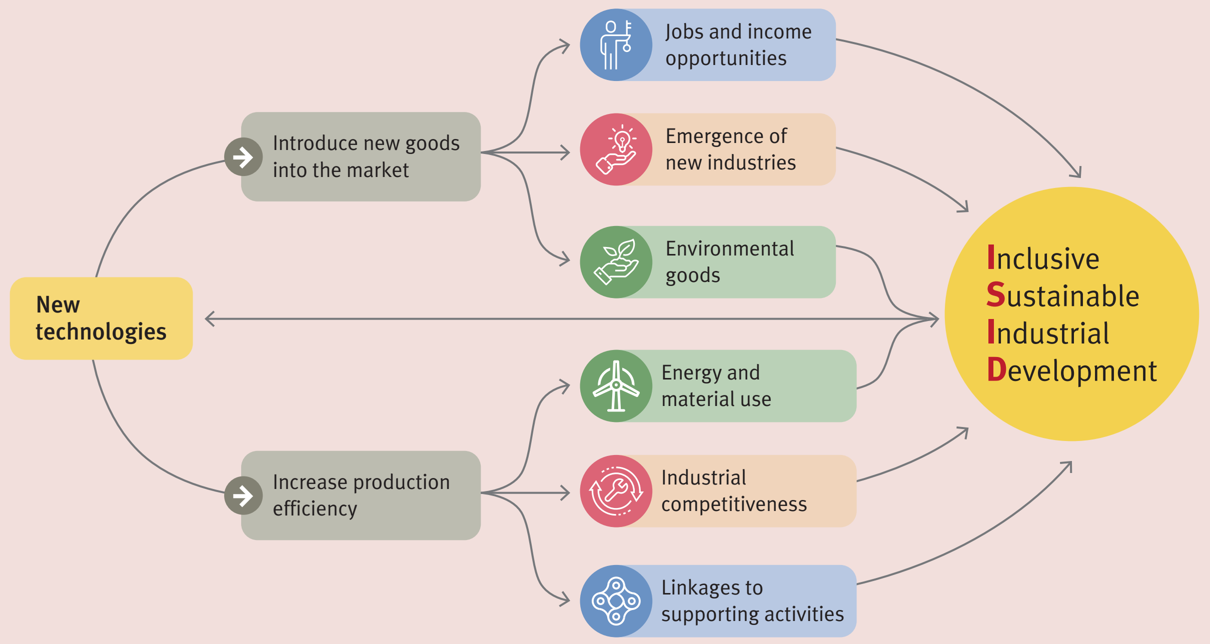
New technologies are at the core of successful ISID. They enable the creation of new goods, which leads to the emergence of new industries. And they support greater production efficiency, which lowers prices and opens consumption to the mass market—or increases profits, with possible follow-on effects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

New industries come from new technologies

New industries—and the incomes and jobs associated with them—ultimately originate from technological product innovations, which support industrialization and social inclusion (see Figure 1.1). When these innovations are geared to reducing environmental impacts —by introducing green manufacturing goods—they

> **"Learning by producing is fundamental in absorbing advanced digital technologies**

Figure 1.1
New technologies and ISID: A conceptual framework



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.

also contribute to the environmental sustainability of the industrial process.

New production technologies increase efficiency

Technological process innovations are key to sustaining and fostering industrial competitiveness and, through this channel, expanding manufacturing production. In many cases, the application of new technologies requires additional inputs and services from other sectors of the economy, thus increasing the multiplier effects of industrial development outside factory boundaries. Greater efficiency is typically associated with reductions in pollutant emissions and material and energy consumption per unit of production, which can make the production process more environmentally sustainable.

New technologies need enlarged human and infrastructure capacities to produce benefits

To work, these mechanisms require several conditions and capabilities, ranging from technical skills and specific infrastructure, to indigenous innovation capacity and well-functioning learning ecosystems. And a feedback loop connects ISID with new technologies: to create and absorb new technologies, countries need to build a minimum base of industrial capacity. As industrialization evolves, the innovative potential of countries also increases. This is shown in Figure 1.1 by a straight arrow going from right to left. As stressed throughout this report, learning by producing is fundamental in absorbing advanced digital technologies. Before looking into these technologies, the chapter provides basic empirical support illustrating the relevance of the various mechanisms in Figure 1.1 connecting new technologies to ISID.

Introducing new goods into the market

Historically, new technologies have led to new products and industries

Most of the goods consumed today are, in one way or another, the result of past technological breakthroughs.

“The emergence of new industries is the result of product innovations

The emergence of new industries is, in fact, the result of product innovations that introduce new goods into the market. From automobiles in the late 19th century to personal computers in the 20th century and to smart devices today, it was a new technological breakthrough (or a combination of emerging technologies) that initiated the rise and expansion of industrial production.

Cars from Daimler to the Ford Model T

In 1885, Gottlieb Daimler built the first vehicle powered by an internal combustion engine, effectively inventing the passenger car (Comin and Hobijn 2010). Eight years later, Charles and Frank Duryea founded the first automobile manufacturing company in the United States, the Duryea Motor Wagon Company, followed by Oldsmobile in 1902 and Cadillac in 1903. Cars were then a luxury good that only very rich households could afford. But everything changed when Ford introduced the Model T in 1908, a low-cost, low-quality car affordable to the middle class (Foellmi et al. 2014). Thus was born the automobile industry—one of the pillars of industrialization in the United States in the 20th century.

Personal computers from hobbyist models to the first Apple

The personal computer story is similar. The first computers were introduced in the United States in the 1950s, but they were so expensive and so large that no individual could use them. Then, in the early 1970s, the invention of the microprocessor made possible the production of the first generation of microcomputers—small enough to fit on a desk and at prices affordable to individuals. But the expertise needed to use them limited their range to a consumer niche of engineers and hobbyists (Greenwood and Kopecky 2013). This changed radically in 1977 when Apple introduced a microcomputer that was both small and user friendly. Thus was born the personal computer industry, another pillar of industrialization in the United States during the 20th century.

Inventions spread from the United States to the world

These product innovations—the automobile and the personal computer—were the drivers of the second industrial revolution (2IR) and third (3IR). In both cases, their emergence and later expansion to the mass market initially took place in the United States and then diffused to the rest of the world. Some years after their invention, they gave rise to two of today’s most important industries, not only in the United States (Figure 1.2) but also in the world.

80 percent of US households had a car by 1968, and 75 percent had a personal computer by 2010

Between 1908 (the Ford Model T) and 1968, the share of households in the United States possessing a car rose from 10 percent to 80 percent. In the same period, the share of transport equipment in total MVA more than doubled, from about 6 percent to 17 percent. The expansion of the market for computers was even more pronounced. In 1977 (the Apple II), only 6 percent of households in the United States reported having a computer. Three decades later, by 2010, 75 percent had one. Between these years, the share of computers and peripheral equipment in MVA more than doubled, from 6 percent to 15 percent.

Cars and computers are now at the heart of US manufacturing value added

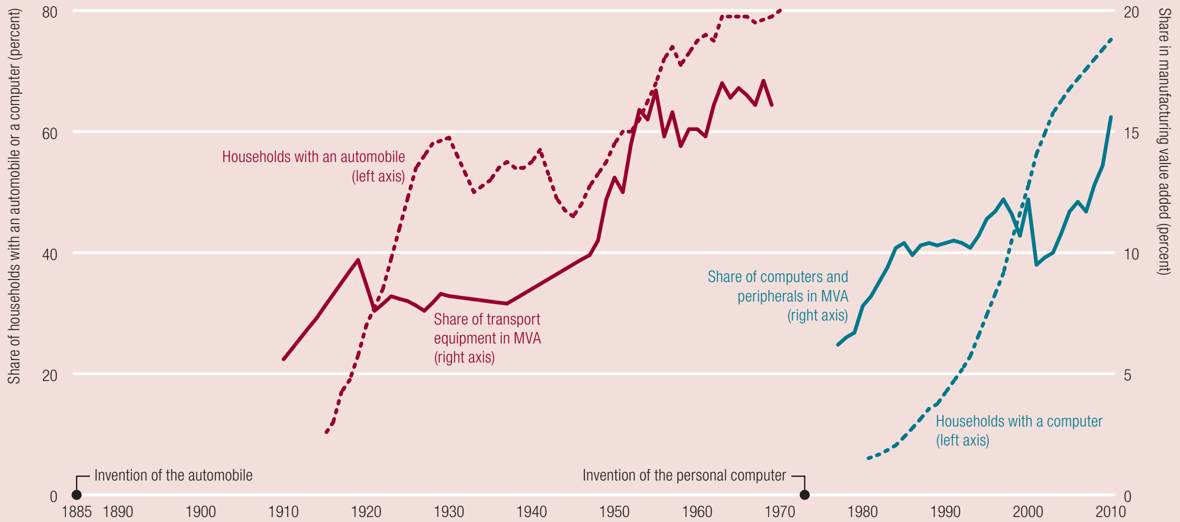
Today, these two industries rank near the top of the US manufacturing sector, with the largest shares of MVA after the chemical industry.[1] But they are also the backbone of manufacturing in many other countries. As latecomer economies absorb the new technology and close the technology gap with the frontrunner, production shifts and new actors take the lead.

New industries boost employment and trigger growth

The new industries (in this case, automobiles and personal computers) constitute a major source of income and employment for the domestic population, due to the direct jobs, profits and wages created not only in that industry, but also in all supporting activities. In addition, the incomes generated, when respent or reinvested, can trigger additional economic growth in what UNIDO’s *Industrial Development Report 2018*

Product innovations can render industrial development sustainable over time

Figure 1.2
The rise of automobiles and personal computers in the United States: Consumption and production



Note: MVA is manufacturing value added. The figure portrays the impressive expansion in consuming and producing these goods in the United States after the initial technological inventions. The dashed lines present the share of households consuming each of these goods (left axis), and the solid lines, the share of each industry in total MVA (right axis).
Source: UNIDO elaboration based on American Community Survey (U.S. Census Bureau 2018), Comin and Hobijn (2010), Felton (2014), Smits et al. (2009), Structural Analysis (STAN) Database ISIC Rev. 3 and 4 (respectively, OECD 2019a and 2019b), UNIDO (2017c), and US Bureau of Economic Analysis (2019a, 2019b).

labelled the “virtuous circle” of industrial development. This is the key channel through which industrialization supports social inclusion, job creation and poverty alleviation. Again, technology is at the core of this process. Using historical data on the automobile and personal computer industries in the United States, Figure 1.3 illustrates this process.

The multiplier effect of new jobs is as big as the effect of the jobs themselves

Two striking features are illustrated by Figure 1.3. First, there is a clear positive trend, pointing to the increasing incomes in the United States created by the emergence and expansion of these industries following the invention of the automobile and personal computer. Second, the multiplier effect on other sectors of the economy tends to be of the same magnitude as the effect in the producing sector. That is, the potential of manufacturing industries to pull up the rest of the economy can more than double the incomes and jobs created, including substantially more of the population in the production process.

Manufacturing environmental goods boosts sustainability

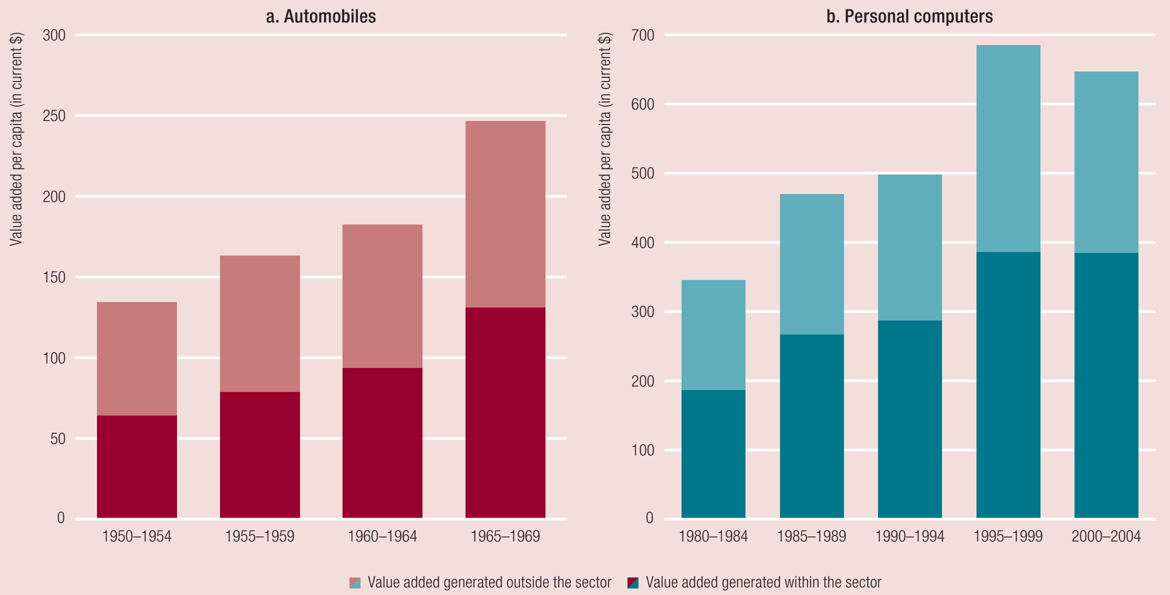
The third channel, presented in the upper part of the conceptual framework (Figure 1.1), indicates that technological product innovations, when geared towards reducing environmental impacts, can also render industrial development sustainable over time. That is, the introduction of environmental goods can contribute much to the sustainability of consumption and production patterns. Manufacturing environmental goods are those that bring “a better quality of life” while minimizing the use of natural resources and toxic materials and the emission of waste and pollutants over the life cycle of the good (UNIDO 2017c).

Consider electric vehicles, which could constitute 50 percent of the world automobile market by 2040

Electric vehicles are an interesting example of a manufacturing environmental good. They require no direct fuel combustion and rely on electricity—the most diversified energy carrier—not only boosting energy

“Electric vehicles could take over up to 50 percent of the world market by 2040

Figure 1.3
Economy-wide income creation by new industries: Automobiles and personal computers in the United States



Note: The figure presents the income per capita generated by the production of these industries in the entire economy, taking productive linkages into account. Input–output techniques estimate the total value added generated by the final consumption of cars (panel a) and personal computers (panel b). Each bar presents the average income generated in a span of five years and distinguishes the portion that corresponds to the same sector (for instance, the automobile industry) and the portion created in other sectors of the economy (for instance, suppliers of auto parts or service providers).
Source: UNIDO elaboration based on US Bureau of Economic Analysis (2019c).

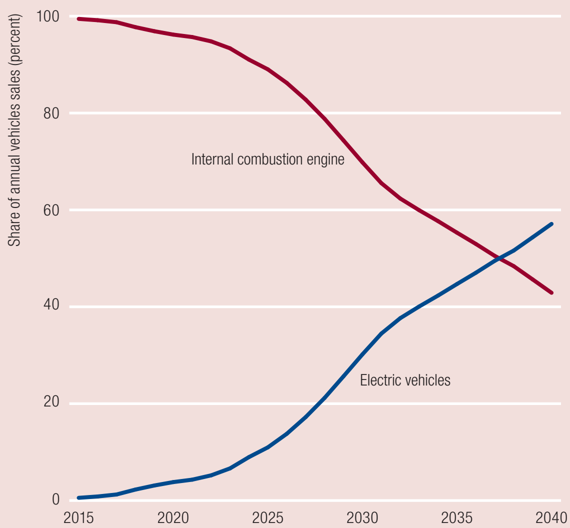
efficiency and reducing greenhouse gas emissions, but also improving air quality and reducing noise (IEA 2018). According to recent projections, electric vehicles could take over up to 50 percent of the world automobile market by 2040 (Figure 1.4). This should reduce the emission of toxic gases, a key step to achieving SDG 13 on climate action.

Fostering production efficiency

New technologies foster production efficiency and consumer affordability

New technologies also foster production efficiency and, in doing so, increase the affordability of manufacturing goods for an increasing share of consumers, as illustrated in the bottom part of the conceptual framework (see Figure 1.1). Country data suggest a clear positive relationship between innovation efforts and production efficiency in manufacturing (Figure 1.5).

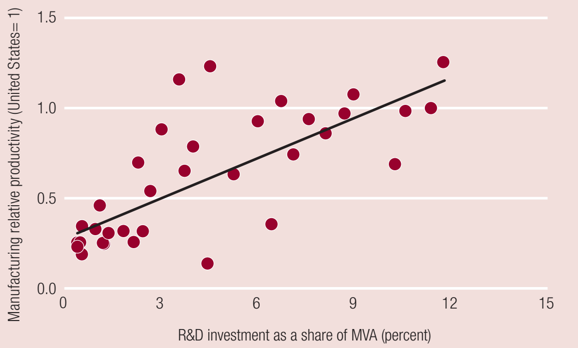
Figure 1.4
The global rise of electric vehicles: Projected sales to 2040



Source: Bloomberg New Energy Finance.

“ Technology has a powerful influence on industrial performance

Figure 1.5
Larger investments in manufacturing research and development are associated with higher production efficiency



Note: MVA is manufacturing value added. R&D is research and development. All values are for 2015 (or closest year). The 34 economies presented in the figure were selected due to the availability of data on R&D expenditures in manufacturing. Manufacturing relative productivity is calculated as the value added per worker (in constant $ 2010) of each economy divided by that of the United States. R&D investments as a share of manufacturing value added are calculated at constant $ 2010.
Source: UNIDO elaboration based on the Analytical Business Enterprise R&D database (OECD 2018a), ILO (2018) and the Manufacturing Value Added 2019 database (UNIDO 2019g).

Countries that invest more in research and development have higher productivity

As Figure 1.5 shows, countries that invest more in manufacturing research and development (R&D) are closer to the frontier in production efficiency. Considering manufacturing in the United States as the global technology frontier and labour productivity as the best proxy for production efficiency shows that countries with higher productivity tend to invest more in manufacturing R&D. This point is supported by a vast empirical literature investigating the positive link between technology development and innovation and productivity for countries,[2] industries[3] and firms.[4]

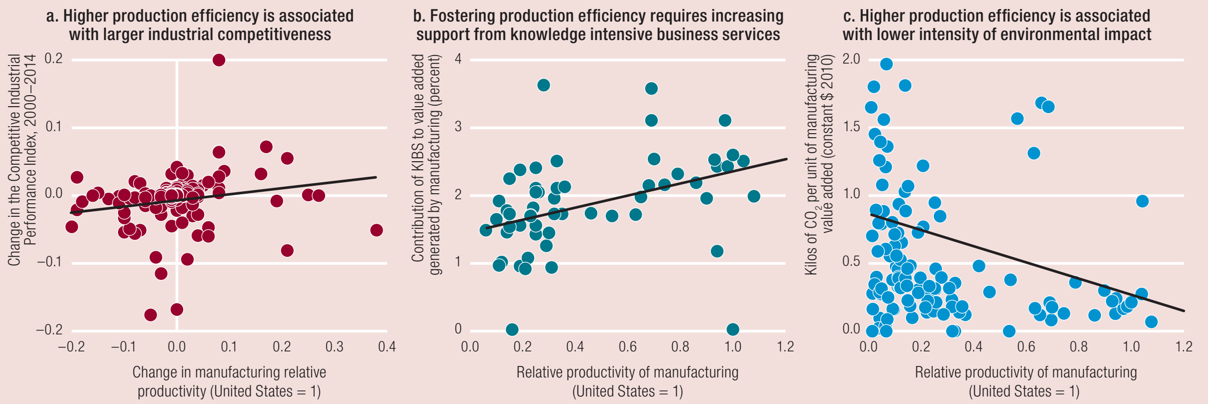
Higher efficiency increases competitiveness and reduces environmental impacts

As the conceptual framework indicates, advances in production efficiency resulting from technological change have important implications for ISID through increased competitiveness, new linkages to supporting activities and the reduced environmental impact of manufacturing production (Figure 1.6).

Countries that improve productivity become more competitive

Technology has a powerful influence on industrial performance through its impact on production efficiency, the key to fostering industrial competitiveness. Panel a in Figure 1.6 provides interesting insights in this respect. It presents the relationship between the changes in relative labour productivity in manufacturing and the changes in countries’ industrial

Figure 1.6
From production efficiency to ISID



Note: KIBS is knowledge-intensive business services. MVA is manufacturing value added. All values are for 2015 in panels a and c and for 2000–2015 in panel b. Panel a includes data for 145 economies, panel b for 57, and panel c for 129. The 57 economies in panel b were selected based on the availability of input–output tables in OECD (2018b). Productivity is calculated as MVA in constant $ 2010 per number of workers.
Source: UNIDO elaboration based on ILO (2018), Inter-Country Input-Output (ICIO) tables (OECD 2018b), the Competitive Industrial Performance Index (CIP) 2019 database (UNIDO 2019c) and the Manufacturing Value Added 2019 database (UNIDO 2019g).

“Increasing linkages to services boosts jobs outside manufacturing

competitiveness between 2000 and 2015,[5] as captured by UNIDO's Competitive Industrial Performance (CIP) Index. The CIP Index is a multidimensional index that assesses the industrial competitiveness of countries along three dimensions: productive competitiveness, technological competitiveness and export competitiveness (see Chapter 5). As panel a in Figure 1.6 shows, countries that reduced their distance to the global technology frontier the most (positive change in relative labour productivity) increased their industrial competitiveness the most (top right quadrant).

Improving productivity requires KIBS

Improving production efficiency in manufacturing by absorbing new technologies also requires more support from other parts of the economy, especially today, when new digital technologies are blurring the boundaries between manufacturing production and services. The corollary of this process is a continuous increase in production linkages between manufacturing and knowledge-intensive business services (KIBS).[6] Panel b in Figure 1.6 shows a clear positive relationship between manufacturing relative productivity and its reliance on KIBS.[7] Manufacturing industries in economies closer to the technology frontier tend to be much more integrated with such services than economies farther from the frontier.

Increasing KIBS helps industry create indirect jobs

An implication of the increase in technology-driven production linkages is that the absorption of new technologies in manufacturing, when supported by other activities, can trigger job creation. Increasing linkages to services (particularly KIBS) boosts the potential of manufacturing industries to create jobs outside manufacturing and thus to support social inclusiveness, particularly for the new digital technologies applied to manufacturing production.

Increasing efficiency promotes environmental sustainability

Panel c of Figure 1.6 illustrates how increasing production efficiency also contributes to environmental sustainability. In this case, the intensity of carbon dioxide emissions in manufacturing production is taken as a proxy for environmental damage.[8] Economies closer to the technology frontier tend to emit less carbon dioxide per unit of production. These emissions are only one dimension of environmental sustainability, but they provide an intuitive picture of the mechanism at play: new technologies, by increasing the efficiency of industries' use of material, energy and labour can lead to more environmentally friendly manufacturing.

New technologies are key to ISID

Studying new technologies is key to understanding ISID, particularly in periods of major changes in industrial technology. A transformative technological transition, driven largely by digital technologies, is under way.

The new technologies shaping the industrial landscape

The steam-, electricity- and computing-driven industrial revolutions

Different waves of technological advances have pushed economic development since the first industrial revolution (1IR).[9] 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 centuries. 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) (Schwab 2016).

Digital production technologies, nanotechnology, biotechnology and new and improved materials

Recent technological breakthroughs seem to be pushing yet another revolutionary wave, in what is commonly called the fourth industrial revolution (4IR). The concept is based on the growing convergence of emerging technology domains and their

> **Smart production results from the application of advanced digital technologies to manufacturing production**

complementarity in production. There is not yet a consensus on which technologies should be considered part of this revolution, and several competing classifications have been advanced. Analysts seem to agree, however, on digital production technologies, nanotechnology, biotechnology and new and improved materials as likely to leave a long-lasting mark on the industrial landscape.[10]

Digital technologies and smart manufacturing

Most of the emerging technologies have applications in all sectors of the economy. When applied to industrial production, these technologies give rise to advanced manufacturing systems (Figure 1.7). A key component of these systems is smart production (or smart factory), which results from the application of advanced digital technologies to manufacturing production.

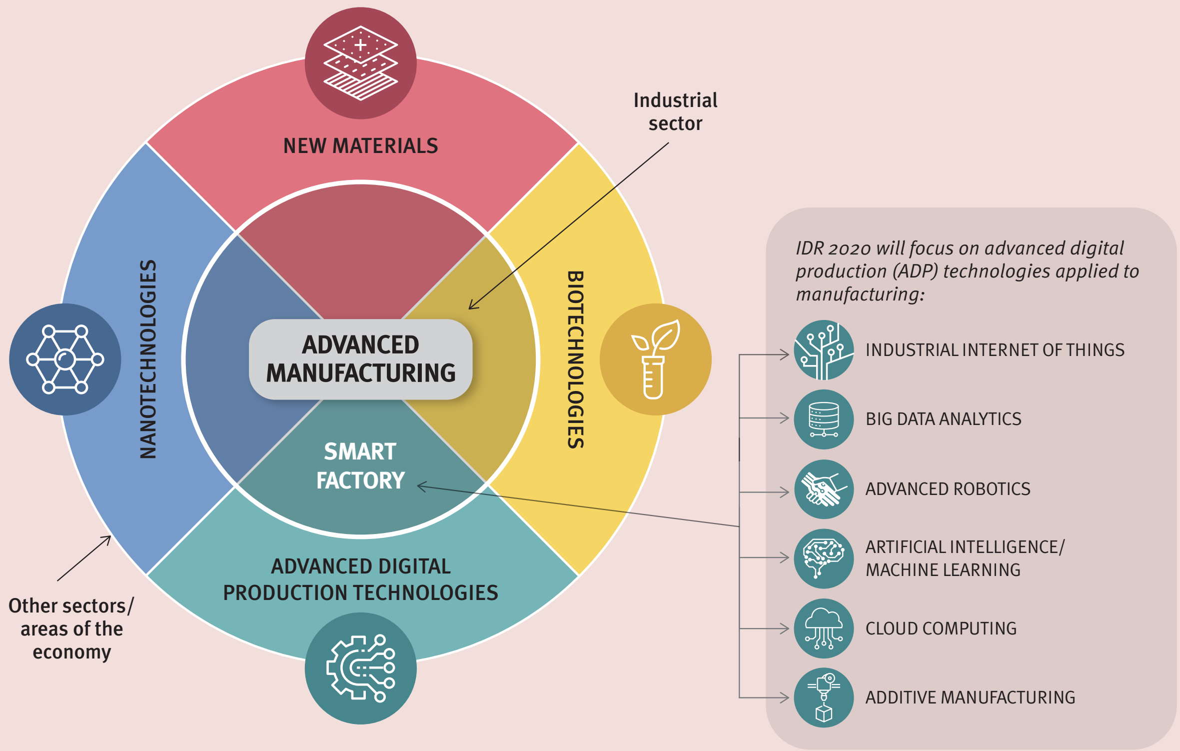
The focus: ADP technologies

Technological advances tend to cluster together and cross-fertilize, so the different domains in Figure 1.7 are actually interconnected. Advances in one technology—for instance, new polymer or composite material—are the result of, and the precondition for, innovation in other technologies, such as additive manufacturing. Leaving these interconnections aside, the main focus of this report is on ADP technologies applied to manufacturing.

Advanced digital production arises from traditional industrial production

Production technologies have driven production transformation since the 1IR. They encompass a wide range of machine tools and tooling and complementary equipment operating in a coordinated and

Figure 1.7
Broad technological domains of the fourth industrial revolution



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

“These technologies evolved from the previous revolutions, suggesting an “evolutionary transition”

synchronized manner to execute tasks to produce goods at the required volume and quality. Production technologies range from simple hand-held tools to highly versatile and complicated equipment with programmable software. ADP technologies are the last in the evolution of traditional industrial production technologies (Figure 1.8). They result from incremental changes in hardware, software and connectivity that have enhanced the possibility of production system integration and smart production (Andreoni and Anzolin 2019). ADP technologies include the industrial IoT, big data analytics, artificial intelligence and additive manufacturing, among others.

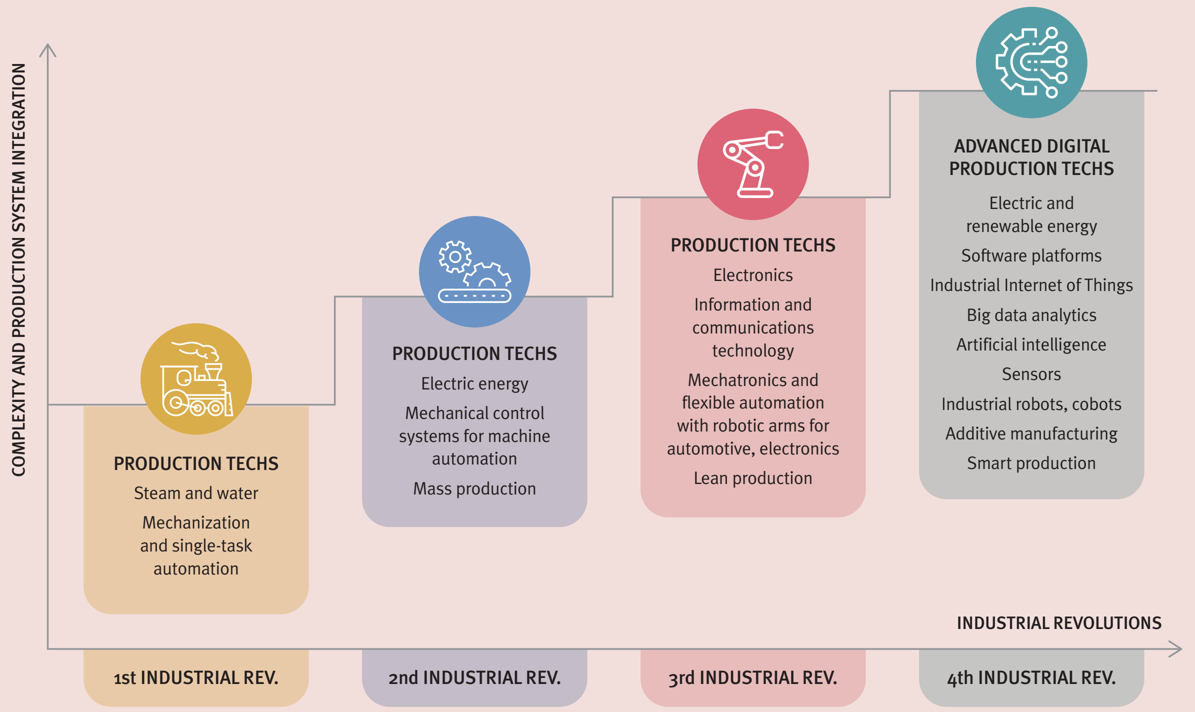
ADP technologies evolve from earlier ones

Many of these technologies have evolved and emerged from the 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 robotics goes back to at least the 1960s. And improvements in operational management and system engineering have always relied on data collection, management and analysis (Box 1.1).

Advanced digital production hardware is a mix of old and new

ADP technologies result from the combination of three main components: hardware, software and connectivity (Figure 1.9). The hardware components are the tools, tooling and complementary equipment of modern industrial robots and intelligent automated systems, as well as cobots (robots cooperating with workers in the execution of tasks) and 3D printers for additive manufacturing. This set of hardware production technologies is largely similar to its predecessor in

Figure 1.8
Production technologies: From the first industrial revolution to the fourth



Source: Andreoni and Anzolin 2019.

> **Production technologies become fully digital once their connectivity is enhanced by software**

Box 1.1
Automation and digitalization: From the first to the fourth industrial revolution

Despite the dominant idea that robots are a new technology, automation dates to the 18th century, when Oliver Evans developed the first completely automated flour mill in 1785. Since then, automation has found application in almost all industries. In the 1950s, machine tools were automated with the help of numerical control languages, which evolved in the 1960s into computerized numerical control that allowed production to rely increasingly on electronics for automation and robotization. The first industrial robot was manufactured by Unimation and deployed at General Motors Company in 1961.

In 1965, General Motors and IBM launched the first computer-controlled production line, which evolved into computer-integrated manufacturing, geometric modelling and computer-aided design (CAD) systems. Throughout the 1970s and 1980s, these new control systems allowed programming machines to execute increasingly complex sequences of tasks with increasing precision. The first microcomputer-controlled robot was commercialized by Cincinnati Milacron in the United States in 1974. Since then, industrial automation has spread to all sectors and countries, with major impacts on productivity. Automation has also become more sophisticated and complex. A distinctive feature of robots in the fourth industrial revolution (4IR) is their greater intelligence and thus problem-solving ability and their interconnection with other machines, enabling coordination (both machine to machine and machine to human) in carrying out common tasks.

The story is similar for the use of data in production. From Taylorism in the 20th century to Japanese lean production to the present 4IR, operation management and system engineering have always been based on data collection and use. During the third industrial revolution (3IR), the diffusion of measurements, standardization and interface standards and the increasingly sophisticated use of data have made possible key production improvements such as the reliance on interchangeable parts and the development of infra-technologies, including metrology systems and testing.

The use of sensors can be traced back to the 3IR. Initially used to better monitor machine maintenance and operations, the data collected by sensors triggered the development of new intelligent platforms to make better use of the huge amount of data produced. Improvements in more sophisticated actuators and sensors, and the evolution from industrial ethernet to wireless networks, created the basis for the high-speed, precise and continuous production of real-time data. The industrial Internet of Things is embedded in these enabling technologies and augmented by integration with cyber-physical systems (CPSs). CPSs are the latest frontier of information-flow software systems and the latest evolution of software used for automation tasks in CAD-CAM (computer-aided manufacturing).

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

the 3IR. What makes these machines different is their connectivity and their flexibility and functionality in executing productive tasks (Boxes 1.2 and 1.3).

Advanced digital production connectivity is one big change from older manufacturing

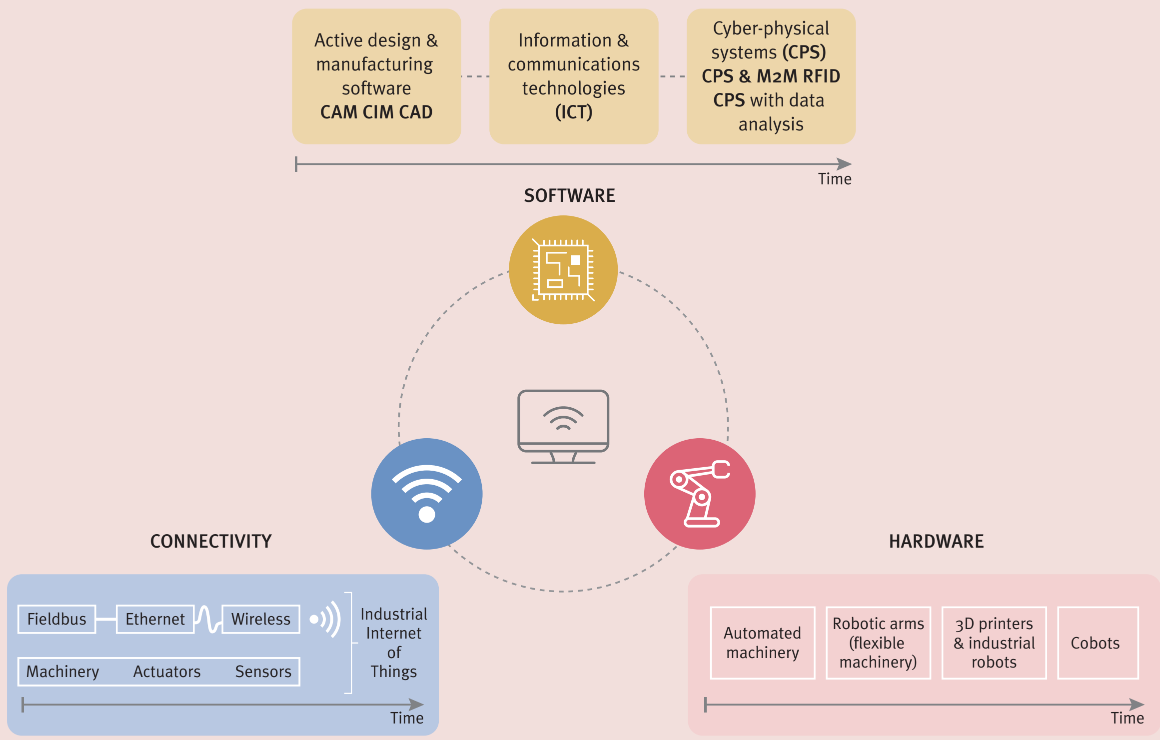
Connectivity in ADP technologies is achieved through sensors in hardware, made possible by equipping machines and tools with actuators and sensors. Once machines and tools are able to sense the production process and products—their components, material and functional properties—they are also able to collect and transmit data through industrial IoT. This type of connectivity opens the way for a paradigm shift from centralized to decentralized production (Box 1.4).

The other big change is advanced digital production software for 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. Since the first software such as computer-aided manufacturing (CAM), computer-aided design (CAD) and computer-integrated manufacturing (CIM) and the improvements offered by information and communications technology (ICT) during the 3IR, the software of the 4IR has opened the way for CPSs. These smart networked systems with embedded sensors, processors and actuators are designed to sense and interact with the physical world and support, in real time, guaranteed

> **Cyber-physical systems can create new production ecosystems**

Figure 1.9
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.

performance in applications (Box 1.5; see also Box 1.8 at the end of the chapter).

Advanced software changes the factory, the supply chain and the product life cycle

Advanced software technologies and their connectivity enable new opportunities for manufacturing integration on three levels:

- Vertical integration of flexible and reconfigurable manufacturing systems and their production of data (smart factory).
- Horizontal integration along the supply chain.
- Product life-cycle integration of digital end-to-end engineering activities.

CPS software makes it possible to capitalize on the full integration of all three levels. For instance, software can integrate data collection, analytics and management for the maintenance of equipment and for stock-level monitoring along the supply chain, enabling machine-to-product-to-machine communication. CPS can thus bridge the virtual and physical worlds to create new production ecosystems where intelligent objects communicate, interact and support an automated self-adjusting process.

The potential benefits of ADP technologies

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

ADP technologies can increase firm profits and capital use, improve environmental sustainability and better integrate the labour force in the production process (Andreoni and Anzolin 2019). Figure 1.10 summarizes the main mechanisms at play, following the conceptual framework at the beginning of the chapter (see Figure 1.1).

> **Cobots are being increasingly adopted in manufacturing firms in advanced and emerging economies**

Box 1.2
Collaborating with the robots

Collaborative robots—cobots—interact physically with humans in a shared workspace. They are designed to collaborate with workers to carry out tasks that ensure greater accuracy and precision in production. One key advantage is the technical features designed to ensure that they do not cause harm when a worker comes into direct contact with them, whether deliberately or by accident (IFR 2018). These features include lightweight materials, rounded contours, padding, "skins" (padding with embedded sensors) and sensors at the robot base or joints that measure and control force and speed and ensure that they do not exceed defined thresholds if contact occurs.

Cobots are being increasingly adopted in manufacturing firms in advanced and emerging economies. The Indian group Mahindra & Mahindra Ltd. (M&M), a dominant player in the tractor and automobile industry, recently installed cobots in its engine and vechicle manufacturing plants and today reports large benefits from quality improvements, cost reduction and increase in safety and environmental sustainability.

M&M is a market leader in the Indian sport utility and multi-utility vehicle sector, and it is the world's largest tractor company by volume. Cobots at M&M support the sealant and tightening application in assembly lines of ring gears, which had previously been done manually, thus improving quality and reducing manufacturing cost. Instead of traditional robots, the company chose cobots as being better suited to work station space and safety conditions. These cobots also have cameras that check and record task quality and allow for real-time monitoring of performance.

The use of cobots, which are designed to work around humans and collaborate with them, eliminated the need for safety fencing and increased the safety of work conditions by reducing the risk that workers would come into direct skin contact with hazardous materials, such as sealant. At the same time, they greatly improved the efficiency and quality of sealant application, reducing hazardous waste. M&M reports that the adoption of cobots has improved quality and precision and resulted in large savings in sealant cost per year, increasing productivity by 8.4 percent.

Source: UNIDO elaboration.

Box 1.3
Manufacturing complex metal parts through 3D printing

Additive manufacturing, commonly called 3D printing, is a manufacturing process that converts a 3D model into a physical object by assembling successive layers of the same material. This technology is the opposite of traditional methods where objects are constructed by successively cutting and removing material from a solid block.

Aerospace is one industry where additive manufacturing is gaining momentum. The French multinational company Thales Group recently opened a centre specializing in metal additive manufacturing in the MidParc Casablanca Free Zone in Morocco. Thales 3D aims to improve the region's competencies in metal 3D printing, and it is the only centre to do this type of production for all the group's subsidiaries throughout 50 countries around the world.

To start production, Thales 3D uses a selective laser melting process to melt successive layers of metal alloy powders using a high power-density laser. So far, Thales 3D has focused on aluminium and titanium, commonly used in aviation. Additive manufacturing allows Thales to produce complex metal parts that cannot be produced with traditional technologies. Moreover, 3D printing allows for easy modelling without the need for complex and expensive moulds.

Source: UNIDO elaboration.

“Cloud technology can enable industrial companies to optimize operations and coordinate different business areas

Box 1.4
Using the Internet of Things for remote control of water treatment plants

The Internet of Things (IoT) refers to the next iteration of the internet, in which information and data are no longer predominantly generated and processed by humans—which has been the case for most data created so far—but by a network of interconnected smart objects, embedded in sensors and miniaturized computers, able to sense their environment, process data and engage in machine-to-machine communication (UNIDO 2017d).

The range of IoT applications is vast, from everyday objects like connected watches, cars, refrigerators or washing machines to specific applications in industrial production. One area gaining attention is water management. Combining IoT solutions with other technological innovations, AVS Technology AG—a medium-size Uruguayan company—is developing small-scale, remote controlled, chlor-alkali production plants.

Chlorine is a key input for water treatment plants. Because production plants are located far from treatment plants, chlorine is sorted, handled and transported as a liquid. There is a high risk of gas leaks, which can seriously harm people and the environment. Such risks are minimized with small-scale plants that can be deployed on the premises of the water treatment plant. Directly injecting gaseous chlorine into the water stream avoids the need for manipulation, storage and transportation of chlorine.

The plants, using the latest automation technologies, are designed to be remotely controlled from Uruguay. Smart sensors collect data on temperature, pressure, pH levels and cell voltage, among other things. The online analysis of the data enables rapid identification of problems that are then solved remotely from company headquarters, greatly improving the plants’ energy efficiency. Moreover, the performance data collected from each plant helps the company improve the structural design of new plants using the feedback obtained from monitoring.

Small-scale chlor-alkali water treatment with remote monitoring is an efficient solution for isolated towns where access to clean water is not guaranteed. AVS Technology AG is starting to explore the African market, where this technological solution could become a game changer for producing potable water at competitive costs.

Source: UNIDO elaboration.

Box 1.5
Improving the accuracy of rubber production through cloud computing and big data analytics

Cloud technology is a general term for information sharing, management platform and other application technologies based on cloud computing. By recording and using production data together with big data analytics and artificial intelligence, cloud technology can enable industrial companies to optimize operations and coordinate different business areas, such as management, communication and R&D.

ZC Rubber, a Chinese company located in the Hangzhou Economic and Technological Development Zone in Zhejiang Province, and one of the largest tire manufacturers in China, adopted Alibaba’s Cloud ET Industrial Brain in 2017. Using intelligent algorithms and artificial intelligence, this tool helps companies collect, analyse and model industry knowledge and data. For ZC Rubber, it is helping optimize the production process.

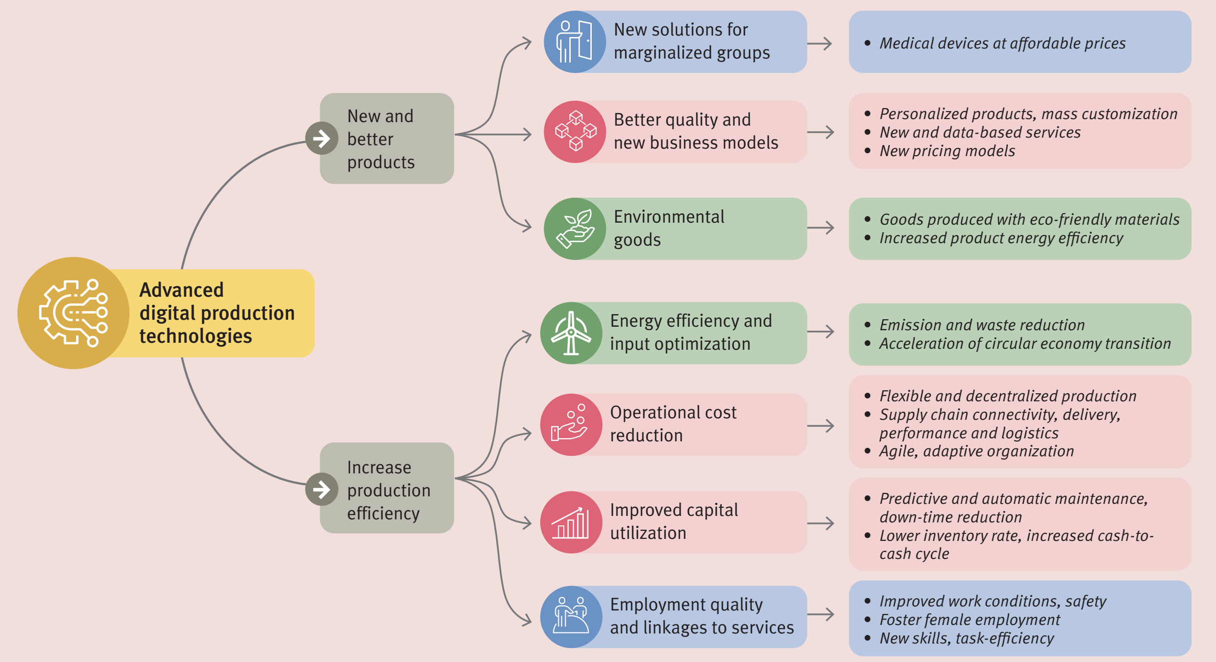
In the past, the production line required manual sorting of rubber blocks. Before the blocks entered the production line, workers had to classify the raw material rubber blocks into a rubber compound according to production area, processing factory and batch. With the Cloud ET Industrial Brain, the company can get real-time data based on process parameters such as the characteristics of the rubber-discharging time and the monitoring results of the rubber compound. For example, temperature stability during the rubber mixing process was improved, increasing energy efficiency. Supported by artificial intelligence algorithms, the tool analyses each piece of rubber and rapidly provides the optimal synthesis and parameters, greatly stabilizing the quality of the rubber compound and reducing the cost for processing.

In the first six months of adopting this technology, ZC Rubber reports that average production and energy efficiency have increased and that the quality of the rubber compound has improved. This increase in product quality and process efficiency led to an increase in the overall value of sales.

Source: UNIDO elaboration.

ADP technologies offer the possibility of revitalizing industrialization

Figure 1.10
Expected dividends from ADP technologies



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

Better products and increased efficiency advance development

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 that will obstruct some of these dimensions. As discussed in the next sections, reaping these benefits depends on conditions specific to each country, industry and firm involved in manufacturing production.

Expanded data analytics are key to improving products and services

The red boxes reflect the potential impacts on industrial competitiveness. ADP technologies can enhance product–service characteristics and functionalities —including product innovation, customization and time to market. 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 and solutions. The changes open new organizational and business model possibilities by attaching services to manufacturing production. In this way, ADP technologies offer the possibility of revitalizing industrialization and boosting economic growth by creating new goods and by blending manufacturing and service activities.

Data quality and access improve labour productivity

ADP technologies can also improve production efficiency or reduce associated costs. The use of big data analytics, for example, provides real-time insights to improve production efficiency. Data-driven decision-making has led to statistically significant increases in

“Adoption and diffusion of ADP technologies are expected to boost economic growth, job creation and poverty alleviation

productivity (Brynjolfsson and McElheran 2016). And improving data quality and accessibility—presenting data more concisely and consistently across platforms and allowing them to be more easily manipulated—is associated with significant increases in labour productivity (OECD 2017). The use of additive manufacturing, in turn, can speed critical stages in scaling up products, while reducing the cost of tooling and retooling for new product and process development.

ADP technologies increase the use of fixed assets

Increasing capital utilization is another channel for ADP technologies to affect competitiveness. This is particularly important for firms operating in developing countries, where capital constraints can be a major barrier for upgrading technology. ADP technologies allow for improving the use of fixed assets, reducing idle times and increasing capacity use. In addition, more flexible robots or 3D printers can reduce investments in multiple automated production lines and the need for investment in tooling and retooling. Predictive maintenance can also bring benefits (Kaziboni et al. 2019). The combination of networked robots, advanced sensors and machine learning allows for immediate self-diagnosis and fault detection, reducing machine down time and providing solutions quickly.

Through productivity gains ADP technologies can support the achievement of SDGs 1, 8 and 9

By supporting competitiveness and productivity gains, the adoption and diffusion of ADP technologies are expected to boost economic growth, job creation and poverty alleviation, thus contributing to some of the prime objectives of UN Agenda 2030, as reflected in the SDG 1 on poverty, SDG 8 on decent work and economic growth and SDG 9 on industry, innovation and infrastructure.

ADP technologies also boost circular economy processes, thus contributing to the achievement of SDGs 6, 12 and 13

ADP technologies also have potential positive impacts on environmental sustainability which, in turn, can also bring dividends and improve capital use. These types of technology are 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.

The circular economy changes the use of materials

In circular economy processes, resource flows—particularly materials and energy—are narrowed and, to the extent possible, closed. Products are designed to be durable, reusable and recyclable, and materials for new products come from old products (UNIDO 2017b). Figure 1.11 summarizes the eight main processes of the circular economy and classifies them along three broad categories—using fewer primary resources, maintaining the highest value of materials and products and changing utilization patterns.

Advanced digital production connectivity, data and IoT boost the circular economy

All these processes can be accelerated by ADP technologies. For example, the increased connectivity of

Figure 1.11
Main circular economy processes

USE LESS PRIMARY RESOURCES

- *Recycling*
- *Efficient use of resources*
- *Utilization of renewable energy sources*

MAINTAIN THE HIGHEST VALUE OF MATERIALS AND PRODUCTS

- *Remanufacturing, refurbishment and reuse of products and components*
- *Product life extension*

CHANGE UTILIZATION PATTERNS

- *Product as service*
- *Sharing models*
- *Shift in consumption patterns*

Source: Rizos et al. 2018.

> **Collected data may provide a foundation for circular economy business models**

people and things through mobile devices has contributed to the proliferation of sharing and product-as-a-service models (Rizos et al. 2018). Through industrial IoT, manufacturers can control and analyse product performance while collecting usage data. In turn, the collected data may provide a foundation for circular economy business models (UNIDO 2017d). Examples include business models where the boundaries between products and services are blurred and manufacturers retain ownership and responsibility for operating equipment. Business models geared towards recycling, remanufacturing or parts harvesting can also benefit from the collection of data on use and operations, providing more information on the condition of parts and thus increasing yields and reducing waste.

3D printing saves energy

The application of ADP technologies to manufacturing processes also opens opportunities for greater energy savings and energy efficiency. Energy savings can arise from optimizing or replacing energy-intensive technologies, from introducing new software tools that optimize energy use or from adapting business processes (UNIDO 2017a). Applying additive manufacturing to the production of parts and prototypes exemplifies the first case. For energy efficiency, introducing these technologies, along with 3D printing, may lead to significant energy savings beyond the industrial sector by introducing product innovations (see Box 1.3). Consider the increasing use of 3D-printed lightweight aircraft components by some manufacturers to reduce fuel consumption. A recent study assessing the energy and resource impacts of 3D-printed lightweight metallic components in the U.S. aircraft industry finds that 3D-printed components could replace 9–17 percent of aircraft mass, reducing overall fuel use (Huang et al. 2016).

New technologies can improve working conditions and workers' involvement

ADP technologies also affect the social dimension of manufacturing production. They can improve working conditions in industrial production by introducing new workflows and task allocations. For instance, automation solutions in the automotive sector have offered opportunities for reorganizing production tasks and moving workers away from the most physically demanding tasks. ADP technologies can also improve working conditions in manufacturing plants. It is standard practice today for workers to manage advanced robots. The increased collaboration between humans and robots is creating a blended workforce. Safety and working conditions on the shop floor are also improved by safety and tracking technologies (see Box 1.2).

ADP technologies can meet some of the consumption needs of marginalized groups

ADP technologies can promote social inclusion also by addressing the product needs of marginalized groups. These groups have been largely overlooked by manufacturing systems based on mass and lean production technologies, whose economic convenience stems from large volumes to lower unit costs. ADP technologies make it possible to design and commercialize highly customized products at a lower price, as the diffusion of 3D printing provides a more economical option for low volumes of manufacturing. The production of high-quality medical devices at a more affordable price is a paradigmatic example (Box 1.6).

New technologies need knowledge-intensive 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 ICT 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 poverty alleviation discussed previously and open new opportunity for countries to enter the manufacturing system. Chapter 2 elaborates on this point and presents evidence suggesting that applying these technologies in manufacturing is associated with greater net job creation and increased social inclusiveness.

Taken together, the technologies described here are shaping a new paradigm in manufacturing

"Technological revolutions have divided the world into leading and following economies

> **Box 1.6**
> **Improving inclusiveness with new affordable solutions for marginalized groups**
>
> Artificial devices to address specific medical needs, such as prosthetic limbs, have been available for a long time. However, their cost typically place them out-of-reach of most people living in developing countries. Thanks to the development and diffusion of 3D printing technologies, it has become possible to manufacture medical devices more quickly and at more affordable prices in developing countries. Kyrgyzstan-based Genesis Bionics is an example of how these new technologies could improve people's lives anywhere in the world.
>
> Genesis Bionics is a start-up company that originated from an Enactus[1] project, which involved students of the Kyrgyz State Medical Academy together with a surgeon specializing in hand surgery and a robot programmer. The company uses computer-aided design programs and 3D printing to manufacture customized bionic prostheses at affordable prices. The typical price for a prosthesis falls in a range between $7,000 and $20,000, while Genesis Bionics's prostheses cost between $1,500 and $2,000. This can make an enormous difference in Kyrgyzstan, where the average monthly salary was around $250 in 2018.
>
> The increased accessibility of 3D printing technology not only reduces the cost of production of such personalized medical devices, but it also guarantees their high quality and functionality. Far from being inferior to other, more expensive solutions, Genesis Bionics' prostheses have a larger battery capacity, which can be charged with ordinary power plugs; are lighter, as they are made of a photopolymer which is very light and strong; and are environmentally friendly, being based on sugarcane and corn. Genesis Bionics also provides an internally developed virtual reality game to train the muscles and improve comfort and precision in the use of the prosthetic hand.
>
> *Note*
> 1. Enactus is a global experiential learning platform, connecting students, academic and business leaders. Guided by educators and supported by business leaders, teams of students identify complex issues in their communities, come up with possible potential solutions, and are supported in the development of community-based projects.
>
> *Source:* UNIDO elaboration.

production and are expected to transform the processes and outcomes of industrial development. The analysis that follows looks in greater detail at the main global players that are creating, producing and using these technologies.

Characterizing the global landscape of ADP technologies

Industrial revolutions have leading and following economies

Technological revolutions have divided the world into leading and following economies, depending on countries' involvement in creating and using emerging technologies. In many cases, however, important parts of the world have been excluded from the ongoing revolution, entering only after several decades, when the technologies were cheap enough and the capability gap had 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.

Identifying the leading economies in advanced digital production technologies

This section characterizes the salient features of the global landscape and the main actors creating and diffusing ADP technologies applied to manufacturing. The analysis is limited by the recentness of these technological breakthroughs (many only in the past few years) and by the incomplete availability of data. The focus is on four technologies: industrial robots, CAD-CAM, additive manufacturing and machine learning. These are the core ADP technologies with data on their inventions and trade, the two dimensions used to characterize countries.

Patents, exports and imports characterize the leading economies

Patent and trade data are used to examine the extent to which different economies are engaging in the global creation, production and use of these technologies. Patent data reveal the innovativeness of economies in these technologies. Export data are used to analyse the competitiveness of economies producing goods

“One striking feature is the extreme concentration of patenting and exporting activity

embodying these technologies, while import data is used to analyse the degree to which economies are using these technologies (see Annex A.1). An underlying assumption of the analysis is that the adoption of these technologies in economies with relatively low patent activity is mainly—if not exclusively—through imports of capital goods embodying these technologies.

Who is doing what?

The top 50 economies in advanced digital production

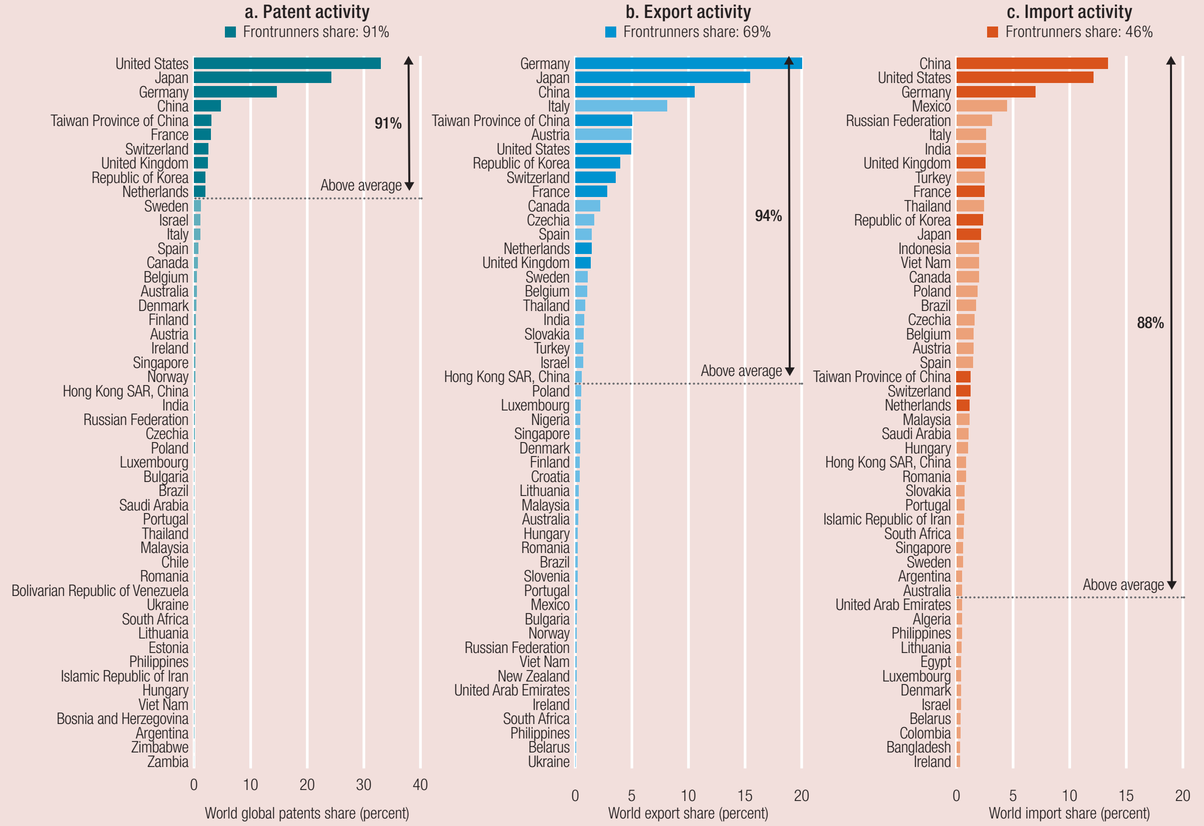
Figure 1.12 provides an early glimpse into how different economies are engaging with ADP technologies. It lists the top 50 economies in the patenting,[11] exporting and importing of these technologies, ordered by their corresponding shares in world totals.

The very top economies explain most of the advanced digital production activity

One striking feature is the extreme concentration, especially of patenting and exporting activity. In both distributions, the average is extremely high, and only a few economies are above it. As a result, the top economies (those above the average) explain most of the world activity in each area—above 90 percent.

Figure 1.12

Patenting, exporting and importing of ADP technologies: Different roles but similar concentration of the top 50 economies



Note: Export and import values are in current dollars. Panel a refers to the cumulative number of global patent families in the last 20 years. Global patents are defined as those simultaneously applied for 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/or the China National Intellectual Property Administration Office. Panels b and c refer to the average export and import values of capital goods associated with these technologies for 2014–2016. The figure shows only the shares of the top 50 economies, but the averages are calculated considering all economies with non-zero values in each indicator. The horizontal line in each panel separates the economies above and below the average share.

Source: UNIDO elaboration based on dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018) and BACI International Trade Database (Gaulier and Zignago 2010).

> ## Ten frontrunner economies account for 91 percent of patents in ADP technology

Ten frontrunner economies account for 91 percent of patents, 70 percent of exports and 46 percent of imports of new technologies

Of the 50 economies with at least one patent in an ADP technology, only 10 show above average market shares. In order, 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. Together, they account for 91 percent of all global patent families. This group leads the rest of the world in creating new ADP technologies. All the economies in this group also have above average shares in world exports and imports of capital goods associated with these technologies (see panels b and c in Figure 1.12). That is, they not only invent the new technologies 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 defined as the *frontrunners* in ADP technologies.

Other economies in the top 50, though with lower values, are also engaging in the new technologies

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.

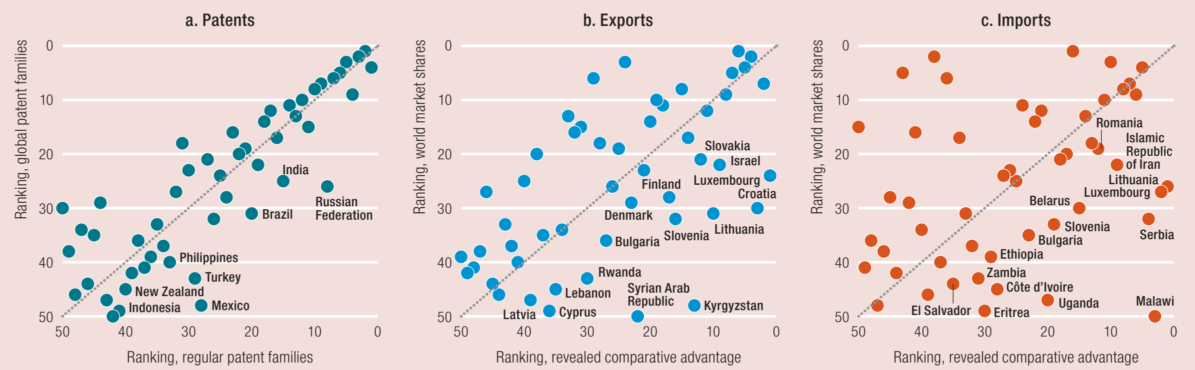
Looking just at global shares may be deceptive: Comparative indices of patents, exports and imports indicate other notable economies

But looking exclusively at world market shares for trade variables could bias the final results, rewarding large economies and penalizing small ones. By the same token, an exclusive focus on global patents might lose sight of important innovation taking place at the country or regional level. Figure 1.13 illustrates how the ranking of economies in each dimension changes using alternative indicators: for patents, using regular (those not defined as global) instead of global patent families, and for exports and imports, using revealed comparative advantage indices instead of world market shares.

How to distinguish followers, latecomers and laggards

To account for these differences, the strategy used for characterizing economies not defined as frontrunners combines both indicators for each dimension and identifies *follower, latecomer* and *laggard* economies. The criteria are based on the average values of the distributions once the frontrunners have been excluded from the sample (see Annex A.1 for the details). Using these

Figure 1.13
Changes at the top with different indicators of patent, export and import activity in ADP technologies



Note: Export and import values are in current $. In each panel, the economies far below the diagonal show a significant improvement in their ranking if the indicator on the horizontal axis is used.
Source: UNIDO elaboration based on dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018) and BACI International Trade Database (Gaulier and Zignago 2010).

> **Large parts of the world remain excluded from recent technological breakthroughs**

averages as thresholds, five additional country groups are identified—followers in production, followers in use, latecomers in production, latecomers in use and laggards—each showing a less intense engagement with ADP technologies than the previous group (Table 1.1).

Frontrunners and followers are actively engaging with ADP technologies

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 activity (latecomers) or very low to no activity (laggards) in the field. The world map in Figure 1.14 illustrates two key features of the global landscape for ADP technologies.

Much of the world, especially in Africa, is not engaging with the new technologies

First, large parts of the world, especially on the African continent, remain excluded from recent technological breakthroughs. These economies are not producing or importing any significant values of the most representative goods within this technological realm. In fact, about half of all economies included in the analysis can be considered excluded from the current wave of technological change.[12]

The roles are diverse among economies engaging in new technologies

Second, even among economies with some activity in ADP technologies, the roles are quite diverse. Latecomers, for instance, have already taken initial

Table 1.1
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 (Frontrunners, Followers in production, Followers in use)

Note: The characterization is for 167 economies that, according to the United Nations Statistical Division, had more than 500,000 inhabitants in 2017. See Annex A.1 for the classification of economies by their level of engagement with ADP technologies
Source: UNIDO elaboration.

> **Without international support, low-income countries run the risk of lagging further behind**

steps to engage with the new technologies, but it is not yet clear whether they will succeed in becoming followers. And among the followers, a large number are engaging in ADP technologies by importing capital goods produced aboard, with very little or no domestic innovating and exporting activity. The prospects for these economies to move up the technological ladder are limited; advancing upward will require large investments in industrial and technological capabilities.

The international community should support lagging economies

These two features call for immediate action from the international community to support developing countries—especially the least developed countries—in adopting ADP technological breakthroughs. Without international support, low-income countries run the risk of lagging further behind and failing to achieve the SDGs. As discussed in the next sections, this support should be oriented towards building basic, intermediate and advanced industrial and technological capabilities, together with digital infrastructure.

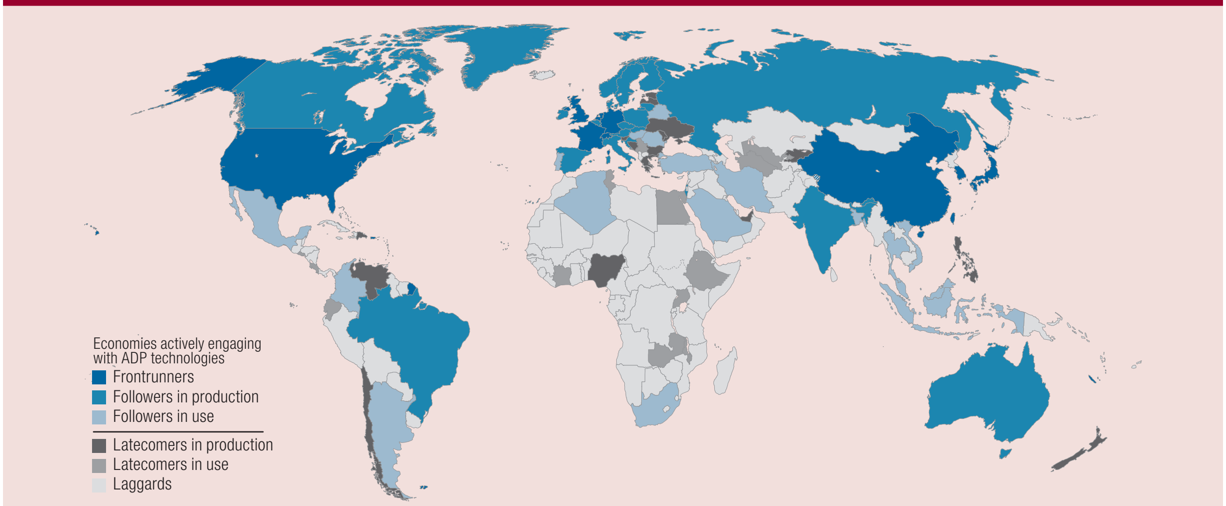
The need for wider industrial capabilities

Developing countries face multiple challenges

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

1. *Basic capabilities.* The production capabilities required for absorbing, deploying and diffusing ADP technologies along 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 systems.
2. *Retrofitting and integration.* Companies in developing countries that could make technology investments in this area have already committed resources to older technologies, and they need to learn how to retrofit and integrate the new ADP technologies into their production plants. Setting up new plants is rarer, because it requires

Figure 1.14
The production and use of ADP technologies are concentrated in a few frontrunners



Note: The map is presented solely for graphical illustration and does not express any opinion on the part of the UNIDO Secretariat concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. See Annex A.1 for the classification of economies by their level of engagement with ADP technologies and Table 1.1 for the description and criteria used in the classification. The category *laggards* also includes economies and territories not elsewhere classified.
Source: UNIDO elaboration based on dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018) and BACI International Trade Database (Gaulier and Zignago 2010).

> **The ADP technology landscape reflects the global heterogeneity of industrial capabilities**

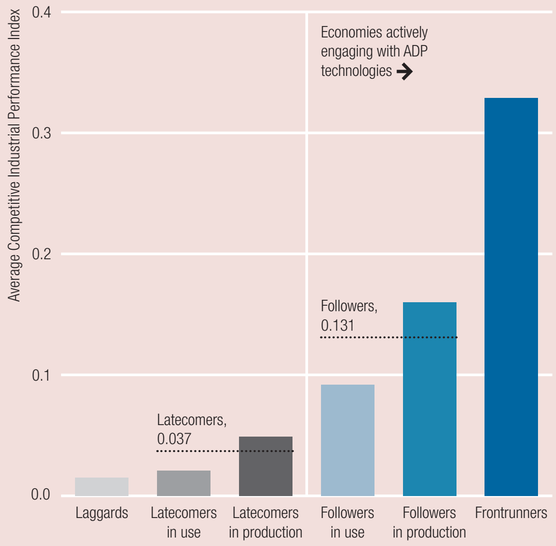
significant long-term investment and access to markets.

3. *Digital infrastructure.* ADP technologies demand substantial infrastructure for their 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.
4. *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 production capabilities to use them. Around these 4IR islands, the vast majority of firms still use technologies typical of 3IR or even 2IR. In this context, it is extremely difficult for a leading company to link backwards and nurture its supply chain. When the digital capability gap is extreme, the diffusion of ADP technologies is extremely limited.
5. *Access and affordability.* ADP technologies tend to be controlled by a limited number of countries and their leading firms. Developing countries rely heavily on importing these technologies. In many cases, even when firms can mobilize the resources to access them, they remain tied to 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 for joining the 4IR. The ADP technology landscape reflects 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 or use. Production (innovating and exporting) requires greater industrial capabilities than use (Figure 1.16).

Figure 1.15
Engaging with ADP technologies requires increasing industrial capabilities



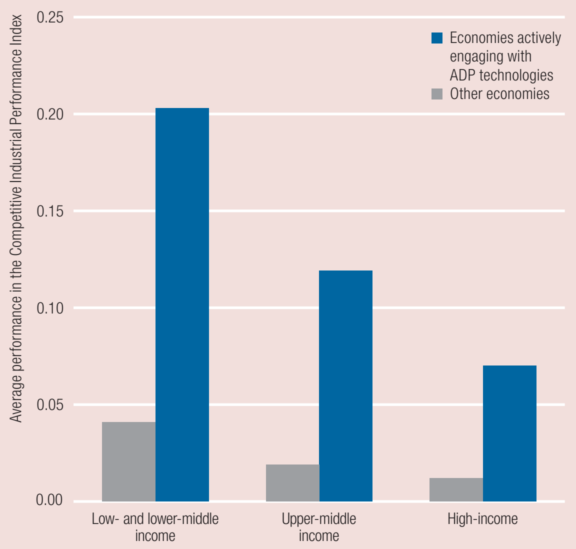
Note: ADP is advanced digital production. All values are average for the year 2017. See Annex A.1 for the classification of economies by their level of engagement with ADP technologies, and Table 1.1 for the description and criteria used in the classification. CIP is Competitive Industrial Performance.
Source: UNIDO elaboration based on the Competitive Industrial Performance Index 2019 database (UNIDO 2019c) and dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018) and BACI International Trade Database (Gaulier and Zignago 2010).

Average Competitive Industrial Performance Index scores differentiate laggards, latecomers, followers and leaders

The Competitive Industrial Performance (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. In 2017, the average CIP Index was much higher among frontrunners than among all other country groups. The followers in production had an average CIP Index value half that of the frontrunners, but higher than that of followers in use. Followers also show larger CIP Index values than latecomers, who rank higher than laggards. Each category has an average CIP Index 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.

“Actively engaging in the new technologies requires building strong industrial capabilities

Figure 1.16
Within income groups, economies actively engaging with ADP technologies show much greater industrial capabilities than the rest



Note: ADP is advanced digital production. All values are average for the year 2017. The analysis includes 140 economies, of which 50 are actively engaging with advanced digital production (ADP) technologies). By World Bank income group definitions for 2017: 53 are low- and lower-middle income economies (of which 4 are active), 38 are upper-middle income economies (of which 13 are active) and 49 are high-income economies (of which 33 are active). See Annex A.1 for the classification of economies by their level of engagement with ADP technologies.
Source: UNIDO elaboration based on the Competitive Industrial Performance Index 2019 database (UNIDO 2019c) and dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018) and BACI International Trade Database (Gaulier and Zignago 2010).

CIP Index values tell more about new technology engagement than country income group

To some extent, these results reflect the fact that frontrunners and followers tend to be richer than the rest. Average CIP values by country income group reveal the same results for economies actively engaging in the new technologies (frontrunners and followers) and the rest within each income group (see Figure 1.16). Within the three income groups (low and lower-middle income, upper-middle income, and high-income), frontrunners and followers have a much higher average CIP: at least five times higher than the corresponding average of latecomers and laggards. In fact, the average CIP values for developing countries (low and lower-middle income and upper-middle income) active in the new technologies are on average larger than the average CIP of high-income economies not yet actively engaged in these technologies. At all incomes, but especially low and lower-middle income, actively engaging in the new technologies requires building strong industrial capabilities.

Dividends from engaging: Growth, employment and sustainability

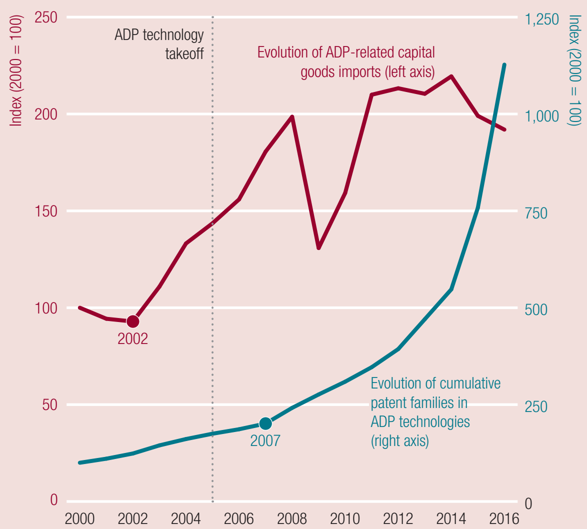
Economies engaging with the new technologies have grown fastest

Economies that engaged in these technologies have grown faster in recent years, showing above average productivity gains but also (in most cases) positive manufacturing job creation.[13]

Digital production technology took off in the 2000s

The technologies embodied in the capital goods analysed for the trade data have been around for a long time, and the data suggest that trade in these goods took off after 2002 (Figure 1.17). For patents, the data allow for a more refined analysis, and the technologies tend to be more recent—those defining today’s

Figure 1.17
The production of ADP technologies takes off after 2005



Note: ADP is advanced digital production. Import values are in current $. The blue line shows the evolution in the total value of imports related to ADP technologies at the world level for three groups of goods: 3D printers, computer-aided design and computer-aided manufacturing (CAD-CAM) equipment and industrial robots. The green line shows the evolution in the cumulative number of patent families in four ADP technologies: additive manufacturing, CAD-CAM, robotics and machine learning.
Source: UNIDO elaboration based on the dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018) and BACI International Trade Database (Gaulier and Zignago 2010).

> **Average MVA growth is much faster for frontrunners and followers than for latecomers and laggards**

frontier in ADP technologies. The evolution of cumulative patents also shows a break, with take-off around 2007. Considering trade and patents together, the take-off of these technologies can be set around 2005.

Growth dynamics differ across country income groups

With 2005 considered the take-off for creating and using these technologies, the dynamics of different country groups in MVA growth, employment creation and productivity gains are examined for 2005–2017. Since growth dynamics are very different across country income groups, the three broad income categories used before (low- and lower-middle income, middle-income and high-income) are analysed separately. For each group, a distinction is made between economies active in ADP technologies (frontrunners and followers) and the rest (latecomers and laggards).

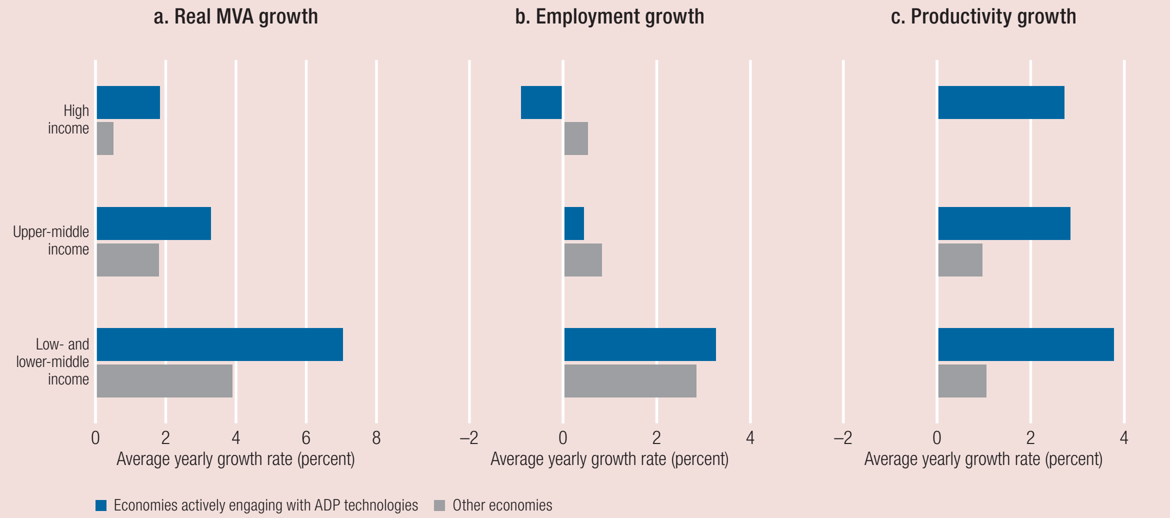
Frontrunners and followers lead in MVA growth because of productivity growth

Average MVA growth is much faster for frontrunners and followers than for latecomers and laggards (panel a in Figure 1.18). In low- and lower-middle income and high-income economies, MVA growth for frontrunners and followers is almost twice that for 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 (panels b and c). The largest differences are observed in the productivity dynamics. Frontrunners and followers are clearly ahead in productivity growth. In developing countries (low- and lower-middle income and upper-middle income groups), frontrunners and followers also show positive growth of employment during this period. In high-income economies, productivity growth more than compensates for a net destruction of jobs during the period (a situation not observable in the high-income latecomers or laggards).

ADP technologies tend towards environmentally friendly solutions

Patent activity in ADP technologies also shows a bias towards environmentally friendly solutions. This is

Figure 1.18
Economies active in ADP technologies grow faster than the rest, across all income groups



Note: ADP is advanced digital production. MVA is manufacturing value added. Each panel shows the average yearly growth rate of the corresponding group and variable between 2005 and 2017. The analysis includes 166 economies (of 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 divided by the number of workers. See Annex A.1 for the classification of economies by their level of engagement with ADP technologies.
Source: UNIDO elaboration based on the Manufacturing Value Added 2019 database (UNIDO 2019g), ILO (2018), and dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018) and BACI International Trade Database (Gaulier and Zignago 2010).

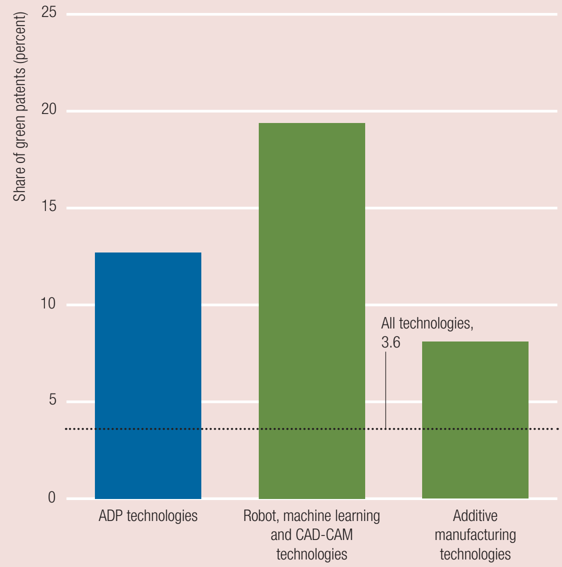
> **ADP technologies have above-average green content**

another important dividend to consider, especially in relation to the conceptual framework (see Figure 1.1).

Robots, machine learning and CAD-CAM systems have above-average green content

ADP technologies have above-average green content (Figure 1.19). This is the case especially for the technologies related to robots, machine learning and CAD-CAM systems and, less so, for additive manufacturing technologies. The most important characteristic highlighted by patent reviewers of these technologies is their potential contribution to mitigating greenhouse gas emissions.

Figure 1.19
ADP technologies have above-average green content



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

New windows of opportunity? Catching up, stage-skipping and leapfrogging

ADP technologies are the tip of the iceberg

ADP technologies require industrial and technological capabilities

Bringing important benefits, ADP technologies also require a very strong industrial and technological base. For that reason, their diffusion around the world remains limited.[14] They can be regarded as the frontier of the broader realm of digital technologies applied to manufacturing production.

Only a small portion of the economy in most countries has entered the fourth industrial revolution

The reality for 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 economy. A salient feature in developing countries is the high heterogeneity both between and within industrial sectors. This heterogeneity is even more evident in the adoption of highly sophisticated technologies.

Developing countries fit incomplete third industrial revolution systems with 4IR technologies

In both developing and advanced economies, the recent applications of ADP technologies coexist with older generations of digital technologies from previous industrial revolutions. Companies in developing countries still use 3IR technologies, often ineffectively. 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—and also for advanced ones—lie in the gradual integration of these technologies within existing 3IR production systems, retrofitting production plants in areas of the firm where integration is possible. A key challenge facing developing countries in everyday operations is how to integrate ADP technologies into existing production operations—that is, retrofitting (Andreoni and Anzolin 2019). For example, capturing the opportunities offered by additive manufacturing in areas such as rapid prototyping (making product design faster and more effective) or tooling (saving on expensive tools or retooling) cannot happen without

> **Firms use a combination of digital technologies emerging from different paradigms**

an effective restructuring of production operations, technology scaling up and organizational change.

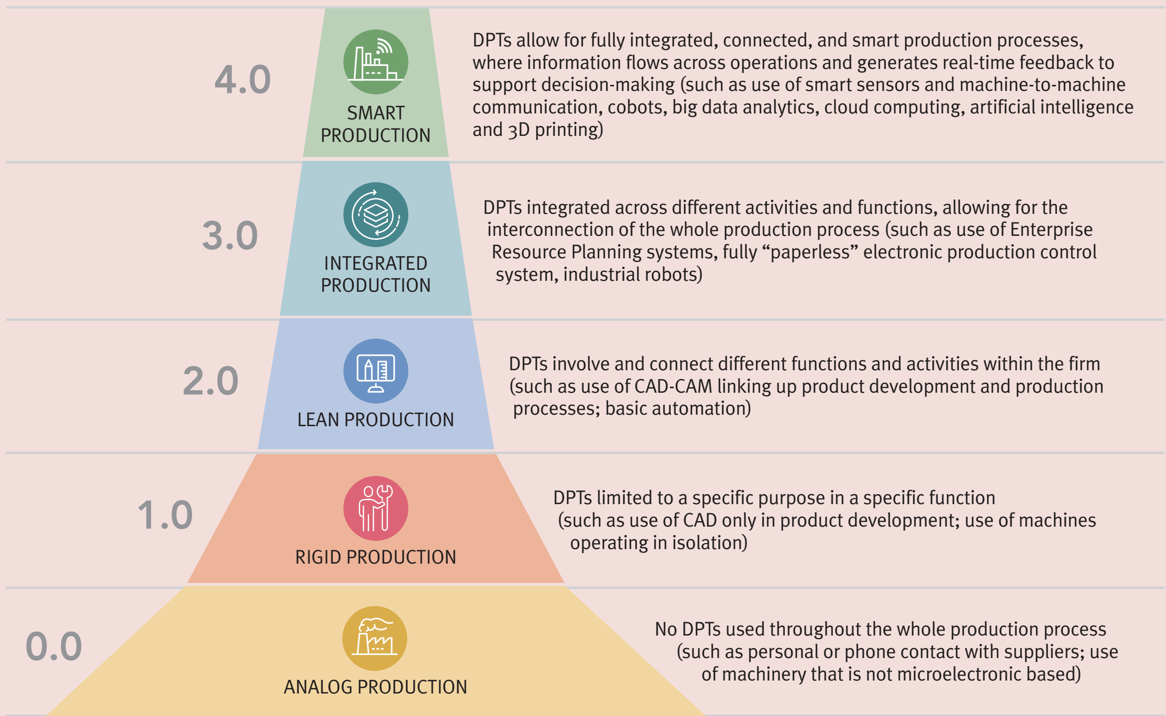
Different technological generations coexist

A taxonomy of generations of manufacturing production, characterized by an increasingly sophisticated approach to the use of digital technologies in production and directly associated with Figure 1.7, can be created by building on the idea that at any given time firms in different countries are likely to use a combination of digital technologies emerging from different technological paradigms (Figure 1.20; Kupfer et al. 2019). These technologies can then be mapped to the specific business functions in which firms are engaged.

Up to 70 percent of firms are still in analog production

The bottom of the pyramid, analog production, represents a very initial stage of production that makes no use of digital production technologies in any area of the firm. This seems to be the reality in the least developed countries and low-income economies. Most of the manufacturing sector in countries defined as laggards falls into this category (Chapter 3 give the example of Ghana, where almost 70 percent of firms surveyed for this report are in the analog category). Once firms start adopting digital production technologies, four generations are distinguished, moving upward from analog production. The first category, rigid production, is characterized by the use of digital applications for specific purposes and in isolation from each other. The second category, lean production, refers to the semi-flexible automation of production with the aid of digital technology, accompanied by partial integration across business areas. The third category, integrated production, entails using digital technologies across all business functions. The fourth and final

Figure 1.20
Four generations of digital production technologies applied to manufacturing production



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

> **Latecomer economies do not simply follow the technological path of advanced countries**

category, smart production, is characterized by the use of digital technologies with information feedback to support decision-making—for example, managing business with big data and support from artificial intelligence.

Generation 1.0 and generation 2.0 of digital production technologies (see Figure 1.20) have been around for as long as numerical control programming systems have existed (late 1950s), though the evolution of devices such as CAD has been exponential in recent years thanks to parametric design.[15] Even if the 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 advanced communications devices, robotization, sensorization, big data and artificial intelligence. Thus, it can be directly associated with the inner green triangle of Figure 1.7.

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 the technology ladder. In particular, can these firms skip some generations of digital production technologies or directly leapfrog to the most advanced? Differences in capabilities, endowments, organizational characteristics, technological efforts, and infrastructural and institutional conditions explain why some firms (and countries) succeed in climbing the technology ladder and others do not.

Moving towards the frontier

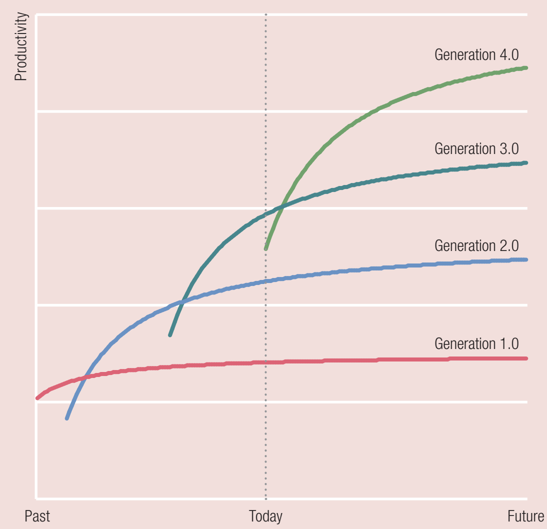
Development by latecomers often includes leapfrogging

Economic development is portrayed by many scholars as a process in which latecomers absorb new technologies and close the technological gap with the world's leading economies. One extended view is that latecomers develop by assimilating and adapting forerunners' obsolete technologies. However, latecomer economies do not simply follow the technological path of advanced countries. Sometimes they skip stages or even create their own paths. By so doing, they might be able to leapfrog older vintages of technology, bypass heavy investments in previous technological systems and move directly to the most advanced emerging technology (Lee 2019).

The newest technology's highest productivity is yet to come

Firms in leading economies today are (on average) using generation 3.0 technologies, the ones yielding the highest productivity (Figure 1.21). The older generation technologies (generation 1.0) have been around for a long time and have reached their maximum productivity. The newest generation technologies (generation 4.0) have only recently emerged. For these technologies, average productivity can still be

Figure 1.21
Leapfrogging in digital technologies for manufacturing production



Note: The figure illustrates conceptually the time trajectory of different technology generations in terms of their average productivity. The curves indicate the level of productivity (vertical axis) associated with the use of that generation at a specific point in time (horizontal axis). The vertical dotted line indicates the present time. For a firm using Generation 1.0 today, a path-following strategy would entail moving to Generation 2.0, a stage skipping strategy would entail moving to Generation 3.0, and a path creating strategy would entail moving to Generation 4.0.
Source: UNIDO elaboration based on Lee (2019).

> **In a path-creating strategy, the latecomer adopts the newest generation of technology**

below that of generation 3.0 but with the best prospects for the years ahead.

A choice between path following, stage skipping and path creating

The experience of the Republic of Korea and other successful economies in South East Asia suggests three archetypical strategies for firms in latecomer economies to catch up with the frontrunners: adopt the old technologies (path following), move to the technology currently used in the leading countries (stage skipping) or jump directly to the emerging technology (path creating; Lee 2019).

Path following uses older technology at low cost

The main advantage of a path-following strategy is that older technologies tend to be readily available at low prices, particularly during business downturns. However, their lower productivity would restrict the chances of being competitive in markets where leading firms are operating. So, latecomer firms should enter a low-end segment of the market while taking advantage of other opportunities, such as lower relative labour costs. This was the strategy followed by the Korean company Pohang Iron and Steel Company (POSCO) when it entered the steel industry in the 1970s (Box 1.7).

Stage skipping enables competition with established producers

In a stage-skipping strategy, the latecomer firm competes directly with firms in the leading economies, provided it has the financial resources to purchase up-to-date technology and can find it in the market or can find established firms willing to transfer it. In this case, the latecomer might emerge as a powerful rival to the established producers since the latecomer will not only enjoy the same productivity level but it will benefit from some degree of cost competitiveness due to the lower relative wages that typically characterize latecomer economies. Again in the case of POSCO, it was precisely through a stage-skipping strategy of adopting up-to-date technologies in the late 1990s that the company managed to forge ahead of the leading company of the time (see Box 1.7).

Path creating has the highest potential but is the riskiest approach

In a path-creating strategy, the latecomer adopts the newest generation of technology. The main advantage of this strategy is that it focuses on the technology with the highest long-term potential (see Figure 1.21). But since the technology is new, this strategy also implies risks because the technology is neither stable nor reliable and has low productivity or high costs in its early stages. It was precisely through a path-creating strategy that Nokia leapfrogged into digital technologies in the mobile phone industry and dethroned Motorola, the world's leading company, by the mid-1990s. And in the early 2010s, Samsung dethroned Nokia by incorporating a new emerging technology—a mobile operating system that was custom built to support the touch interface that later became a standard feature of smart phones.

Adopting emerging technologies is key to advancing

A key question for firms in today's laggard and latecomer countries is what strategy to take to become followers. An important historical insight is that latecomers do not have to invent new technologies. Instead, their main entry point could be to rapidly adopt emerging technologies or adapt them to local conditions through incremental, follow-on innovations with local twists. The experience of some of the most successful manufacturing firms in East Asia suggests that learning is not possible without adoption. Samsung and Hyundai Motors in the Republic of Korea started by adopting foreign technology for production and learned by using it before enhancing productivity by mastering these technologies (Lee 2019).

Opportunities for latecomers

Latecomers are not constrained by prior investments

The world map in Figure 1.14 reveals a pessimistic view of the global landscape of ADP technology

> **“In times of paradigm shifts, new windows of opportunity emerge for latecomers**

Box 1.7

Leapfrogging and leadership changes: Examples from the steel industry

U.S. firms dominated steel production during the first half of the 20th century. By the 1970s, the U.S. leadership had eroded, and Japan eventually became the leader in 1980. Fifteen years later, by the mid-1990s, a company from the Republic of Korea, Pohang Iron and Steel Company (POSCO) surpassed the top Japanese steel firm, Nippon Steel, and became the world leader. As documented in Lee and Ki (2017), these changes of leadership are closely associated with the windows of opportunity opened by technological breakthroughs in steel production.

The steel industry is slow to innovate, and some of its process technologies have been used for decades. For instance, open-hearth furnaces (OHF) had been dominant for five decades when the revolutionary basic oxygen furnace (BOF) was put into commercial operation in the 1950s. Another example is continuous casting, which was commercialized in the 1960s and maintained its dominance for the next 40 years.

Japan's forging ahead in the second half of the 20th century was stimulated by the rapid adoption of BOF technology, which was 10 times faster at refining liquid iron into crude steel than the then-dominant OHF. However, when BOF was introduced in the 1950s, it had numerous problems, including causing tremendous pollution, having a narrow scope of applicability in steel production and causing the brick lining of furnaces to deteriorate. Although BOF was expected to eventually stabilize, no one could anticipate when this would happen and how much the technology would boost productivity and lower costs relative to the stable, proven and still incrementally improving OHF. For firms, especially in the United States, existing OHF equipment remained economically viable, and they were very slow to adopt the new technology. In contrast, Japanese firms moved quickly to adopt BOF and introduced follow-on innovations that solved its two major problems—slags slopping and exhaust gas emission. This strengthened the advantage of BOF over the old technology and promoted its spread. By the 1970s, rapid adoption of the new technology had made Japanese firms more productive than firms in all major world players, including the United States.

The Republic of Korea forged ahead in a different way. In the 1970s, Korea was still a latecomer in the industry, without significant production. It first adopted a gradual catch-up, path-following strategy, focusing on low-end products. POSCO was established as a state-owned enterprise in 1968 and signed cooperation agreements with Nippon Steel Corporation to get guidance on technical details. POSCO followed the Japanese path and used technologies that were relatively outdated at the time. Facing formidable competition in high-end segments in the 1970s and 1980s, and having weak technological capability, POSCO found its niche at the low end of the steel industry, producing such products as hot-rolled coil and thick plates, rather than high-end products such as coated steel and alloy steel.

During the second oil crisis, POSCO was able to move to a fast-follower position by introducing state-of-the-art technologies at low cost. Purchasing and installing the latest technologies (such as continuous casting) and facilities at low cost laid the basis for POSCO's new cost advantages. This paved the way for matching and then surpassing the productivity of Nippon Steel Corporation in the late 1990s. During this period, POSCO also moved from low-end to high-end products, matching Nippon Steel Corporation's share of high-end products.

Today, the important breakthroughs that advanced digital production technologies are bringing to manufacturing might open windows of opportunity for other economies, such as China, to leapfrog and take the lead in the global steel industry (see Box 1.8).

Source: UNIDO elaboration based on Lee and Ki (2017).

creation and diffusion. Most the world's countries are either latecomers or laggards, with no or marginal engagement with new technologies. History shows, however, that latecomers might have some advantages when adopting new technologies since they are not constrained by large investments in old technologies. So, in times of paradigm shifts and technological breakthroughs, new windows of opportunity emerge for latecomers to catch up technologically (Lee 2019).

Small start-up firms have advantages in exploiting opportunities

Start-ups and young small and medium-sized enterprises (SMEs) in developing countries might be better positioned to exploit windows of opportunity than established firms. These firms are less likely to be complacent about existing technologies or business models. They have no sunk investment in old or exiting technologies and business models and are thus more inclined to switch.

> **"Leapfrogging into emerging technologies requires policy support**

Trying to leapfrog creates risky choices

Leapfrogging into new emerging technologies comes with risks. Opting for an emerging technology is risky because new technologies tend to be more unstable initially, and outcomes are uncertain. In addition, several competing standards emerge simultaneously, and it is difficult to identify which will become dominant. Investing in the wrong technology would mean failing to gain returns in the long run. When firms from the Republic of Korea considered entering the cellphone industry, the analog system was still dominant in the United States while the time-division multiple access (TDMA) system was dominant in Europe. Authorities in the Republic of Korea opted for an emerging alternative technology, the digital-based code-division multiple access (CDMA) system, which had higher efficiency in frequency use and higher quality and security in voice transmission. So, despite great uncertainty, the government developed the world's first CDMA system, a key milestone in the country's rise as a major world producer of cellphones.

Latecomers need research and development capabilities to leapfrog

Risks apart, leapfrogging requires minimum levels of technological and production capability. The first step for a firm in a latecomer economy is to build up to a certain level of capability in production technology. This typically requires independent R&D efforts to build a solid technological base. But being able to leapfrog also requires access to the global knowledge base—without it, technological catch-up is very hard. Leapfrogging demands a combination of production capability of the latecomer firms and seed technology from the leading countries' firms.

Adopting ADP technologies requires new public policies and subsidies

Leapfrogging into emerging technologies also requires policy support. Without subsidies or incentives from the government, few firms in developing countries would take the risk of adopting new technologies because of weak demand during the initial entry stage. So, it would be hard to achieve the required production volume to compete with established firms from leading economies. Implementing ADP technologies requires new forms of public policy and public–private partnerships with coordinated support from different government agencies and public–private R&D consortiums. Through these consortiums, the government can support large projects that are difficult for private firms to finance alone. These collaborative entities can also reduce the risks associated with the choice of technology by pooling knowledge from the private sector, universities and public R&D agencies. They can also act as a "technology watch" to interpret and monitor the state of the art of R&D activities around the world and help local producers adopt and absorb these technologies.

Country possibilities depend on industrial structure, domestic firm capabilities and policies

Thus, the possible responses of countries to the 4IR and the opportunities these technologies might open depend to a large extent on their industrial structure (Chapter 2), the domestic capabilities of firms (Chapter 3) and the industrial policy to get ready for the new technologies (Chapter 4).

Manufacturing is still important

The diffusion of ADP technologies depends on cost-effectiveness and digital capabilities

ADP technologies are expected to coexist with older generations of digital production technologies for a long time, especially in developing countries. Their diffusion will be determined by several factors, including how close the technologies are to being the most cost-effective way to produce certain components or products. Especially important is the extent to which firms in developing countries can meet the basic capability threshold and catch up with the world frontier. They need to build a sufficient bundle of capabilities in several functional areas to increase their opportunities to leapfrog closer to the technology frontier (Box 1.8). Without these capabilities, their chances

> **Industrialization is fundamental for embarking on a 4IR learning pathway**

Box 1.8
Leapfrogging to ADP technologies in steel production

Rapid advances in advanced digital production (ADP) technologies are creating intelligent plants in the steel industry, significantly improving production efficiency. The Chinese Baowu Steel Group—the main actor in China's steel production—is taking steps in this direction. The company has used digital technology for 30 years, but it still lags behind international leaders, especially in system operation maintenance, logistics management and integration of the stages of production.

To address this gap, Baowu cooperated with Siemens in 2016 to implement ADP technologies in steel production. Siemens supported Baowu's upgrading to smart production by adopting COMOS in several production plants, an engineering and management software that enables remote intelligent monitoring, mechanical diagnosis, fault warning and equipment end-of-service prediction. Baowu expects this technology to boost average daily output by 15–30 percent and reduce excess warehouse inventory by half. In some plants, the company already reports increases in labour efficiency of about 10 percent and overall cost reduction of 20 percent. The application of new technologies—artificial intelligence, edge computing, augmented reality and industrial cloud—are expected to reduce the factory's non-conforming product rates by 28 percent, to increase operational efficiency by 30 percent and to extend equipment effective-operation time by 35 percent.

Adopting this technology is also creating safer working environments. By eliminating the safety hazards of manual operations, intelligent manufacturing has decreased the risks for steel workers. The integration of controllers and radio frequency identification technology, for instance, created a "smart brain" for the robots operating in the plant, improved the accuracy and efficiency of refueling operations and eliminated the safety hazards of manual operations. Lifting molten metal is the most dangerous task for steel workers. One key output from this collaboration was the joint development of China's first fully automated intelligent molten metal crane, in stable operation since 2018.

Baowu's preexisting capabilities and knowledge in steel production facilitated its technological upgrade of the production line, as setting up the digital production systems for steel production required expertise in the basic parameters used in traditional processes. Given its long experience in the steel industry, Baowu could provide Siemens more accurate and rich data for setting up the new digital system. In addition, Baowu's steel workers' experience with the previous production line and management system made it easier to upgrade to new technologies.

Source: UNIDO elaboration.

of leapfrogging will be very limited (Andreoni and Anzolin 2019).

Industrialization is the pathway toward the fourth industrial revolution

Against the common claim that industrialization is no longer a viable or feasible path towards development, the analysis in this chapter suggests a very different view. Industrialization and the manufacturing sector are fundamental for embarking on a 4IR learning pathway and capturing its digital dividend, for at least three reasons.

Manufacturing is central to developing productive capabilities

First, manufacturing companies remain the main learning centres of any industrial revolution, especially for the development of digital production technologies (Andreoni and Anzolin 2019). This is due to the complex nature of manufacturing processes; the widespread adoption of interdependent sets of machines, tools and equipment; and the broad range of specialized skills and R&D required in manufacturing production. As Chapter 3 shows, manufacturing industries are central in developing the basic and intermediate productive capabilities that firms need to efficiently deploy, effectively organize and incrementally absorb new technologies.

The 4IR stems from earlier manufacturing technologies

Second, the 4IR ultimately stems from 3IR technologies—hardware, software and connectivity—and organizational principles. When nonmanufacturing sectors capture the digital dividend, it is because 3IR and 4IR technologies are used to manufacture their transformation (Andreoni and Chang 2019).

> **The application of ADP technologies to services has remained in activities that do not deliver structural transformation**

Services using ADP technologies do not spur much production

Third, across developing countries, the application of ADP technologies to services has remained concentrated in activities that do not typically deliver the type of structural transformation countries need. For example, the increasing use of ICT in mobile communications and financial transactions, especially in countries like Kenya and Nigeria, has provided important services to communities. But the use of these technologies in production remains limited. The digital dividend will be higher when ADP technologies are used in production-related services closely linked to manufacturing, such as engineering design services, market analysis, logistics and e-commerce. To establish this symbiotic relationship, a relatively sophisticated manufacturing base must be developed first.

Notes

1. According to Industry Economic Accounts Data of the U.S. Bureau of Economic Analysis (2019b), chemical products were the largest manufacturing sector in the United States in 2017, with 16.2 percent of MVA, followed by transport equipment (14.1 percent) and computer and electronic equipment (12.9 percent).
2. See, for instance, Griffith et al. (2004).
3. See, for instance, Griliches (1979, 1988), Guellec and Van Pottelsberghe de la Potterie (2004), and Pieri et al. (2018).
4. See, for instance, Dosi and Grazzi (2006), O'Mahony and Vecchi (2009), and Parisi et al. (2006).
5. For all figures in this section, relative productivity measures (and their change) are calculated against labour productivity of United States' manufacturing.
6. The *servicification* of manufacturing and its implications for innovation and technological change have been long studied in the literature. A recurring conclusion is that the increasing fragmentation of production and the organizational complexity of economic systems have strengthened the need for services, both as productive inputs (Guerrieri and Meliciani 2005, Peneder et al. 2003) and as auxiliary elements in the production of industrial goods (Bryson and Daniels 2010, Francois et al. 2015). KIBS, in particular, have been regarded as important carriers of new knowledge within the economy (Berardino and Onesti 2018, Francois et al. 2015) that can enhance productivity growth and competitiveness (Baker 2007, Castaldi 2009, Ciriaci and Palma 2016, Francois and Woerz 2008).
7. KIBS are broadly defined as sectors C71RMQ (*Renting of machinery and equipment*), C72ITS (*Computer and related activities*), and C73T74OBZ (*R&D and other business activities*) from the OECD's Inter-Country Input-Output Tables (ICIO). The reliance of manufacturing on KIBS is estimated using multiregional input–output techniques on the OECD ICIO (see Annex A.2.1).
8. The environmental impact of industry can be captured through a wide range of indicators. Panel c of Figure 1.6 concentrates on carbon dioxide emissions and looks at the intensity of emissions per unit of MVA.
9. This section is based on the background contribution prepared by Andreoni and Anzolin (2019).
10. See, for instance, OECD (2017), Schwab (2016), UNCTAD (2018), UNESCAP (2018), and UNIDO (2017d).
11. Figure 1.12 focuses on global patent families. These are defined as patents 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/or the China National Intellectual Property Administration Office.
12. Note that 88 of the 167 economies are defined as laggards.
13. It is not possible to attribute causation. Factors beyond technology adoption also contribute to value added and productivity growth. Moreover, fast-growing economies tend to show higher investment rates and

embodied technical change, so causation can also run from growth to technology adoption.

14. This section is based on the background contributions prepared by Albrieu et al. (2019), Kupfer et al. (2019), and Lee (2019).

15. Parametric design refers to the creation of 3D geometries piece by piece. That is, 2D sketches turned into 3D features, with constraints and relations duly applied to fit the designer's goal.

Chapter 2

The evolving landscape of industrialization under advanced digital production technologies

Chapter 1 presented the different roles of countries in the emerging landscape of advanced digital production (ADP) technologies. China and some advanced economies have been dominant in both innovation and exports, while a handful of emerging industrial economies have contributed to both. The remaining economies, especially in Africa, are either ADP users only or have yet to engage in any way with such technologies. This chapter moves from the global perspective of Chapter 1 to a country perspective, looking at the effect of ADP technologies on the structure of manufacturing industries and on social inclusion through employment.

The path of a country's technological change is determined by industrial sector changes

A country's pace and direction of innovation and technological change are determined by differences in the technological intensity and the speed of technological change in individual industries. Specifically, the heterogeneity of technological orientations and the impact of ADP technologies on individual industries arise from:

- Differences in the sectoral diffusion of technologies that might affect some industries more than others.
- Impacts of the new technologies within sectors, which would affect productivity and factor intensity.
- Impacts of new technologies on intersectoral linkages through the provision of supporting activities.

For insights about the divergence in country engagement with ADP technologies, the chapter looks into differences in the underlying sectoral structure and technological orientation of individual industries.[1]

Changes in industrial structure drive changes in employment

Changes in industrial structure and ways to organize production along supply chains arising from the adoption of ADP technologies affect the inclusiveness potential of industrial development. The effects these changes are likely to have on employment opportunities depend, to a large extent, on the skill and gender of workers. Besides the direct impact on employment, ADP technologies shape employment potential through backward and forward linkages and income effects. Most studies look only at the direct impact, but for effective policy-making, countries need to consider the net employment effects of ADP technology by examining all transmission channels.

ADP technologies and the structure of manufacturing

Some manufacturing industries are more likely than others to adopt new technologies

ADP technologies are not found in all industries even in frontrunner economies. Within a country, differences in technological intensity and production process make some manufacturing industries more likely to adopt new technologies than others. This heterogeneous advance across industries implies a close relationship between a country's new technology development and its industrial structure.

The computer and transport equipment industries are most likely to adopt ADP technologies

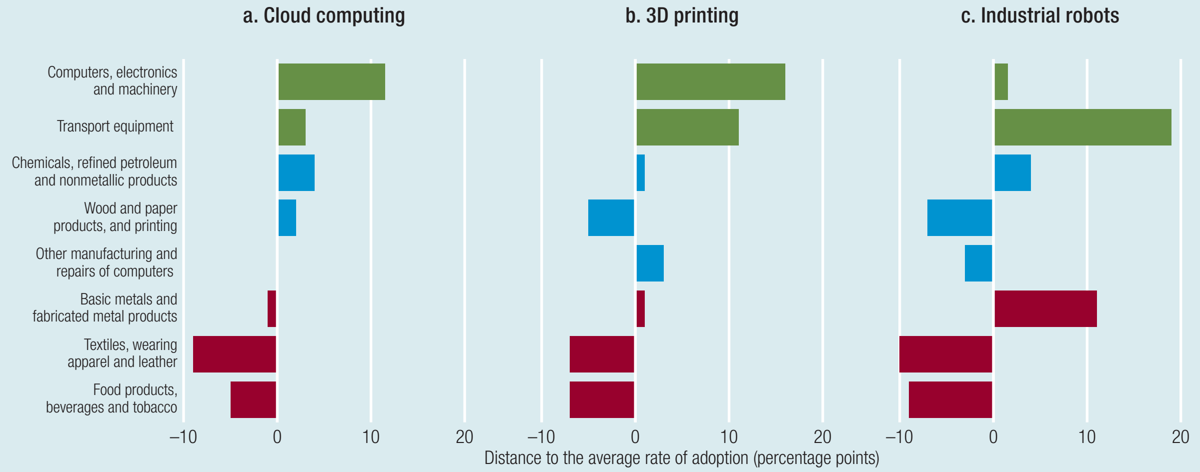
Figure 2.1 shows differences in the diffusion of key ADP technologies across industries relative to the average rate of adoption across manufacturing. The computer and machinery industry and the transport equipment industry are most active in using those technologies. The computer and machinery industry has the highest use of cloud computing and 3D printing technologies, at 10–15 percentage points above the average for manufacturing, while the transport equipment industry is ranked second and tops the use of industrial robots in manufacturing.

The computer and transport equipment industries are technology and digital intensive

Table 2.1 uses two common typologies—the technology and digital intensity of sectors—to classify

> **The productive structure of countries has a key role in determining the diffusion of ADP technologies**

Figure 2.1
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. Adoption rate is defined as the percentage of firms in an industry using a chosen technology. Due to data availability, chemicals are presented together with refined petroleum and nonmetallic 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 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. (See Table 2.1.)
Source: UNIDO elaboration based on Eurostat (2019).

Table 2.1
Typology of industries by digital intensity and technology intensity

		Digital intensity	
		Low and medium-low	**Medium-high and high**
Technology intensity	**Low and medium-low**	• Food products, beverages and tobacco (ISIC 10t12) • Textiles, wearing apparel and leather (ISIC 13t15) • Coke and refined petroleum products (ISIC 19) • Rubber and plastics products (ISIC 22t23) • Basic metals and fabricated metal products (ISIC 24t25)	• Wood and paper products, and printing (ISIC 16t18) • Other manufacturing (including furniture) and repairs of computers (ISIC 31t33)
	Medium-high and high	• Chemicals and pharmaceutical products (ISIC 20t21)	• Computers, electronics and machinery (ISIC 26t28) • Transport equipment (ISIC 29t30)

Source: UNIDO elaboration based on Calvino et al. (2018) and OECD (2011).

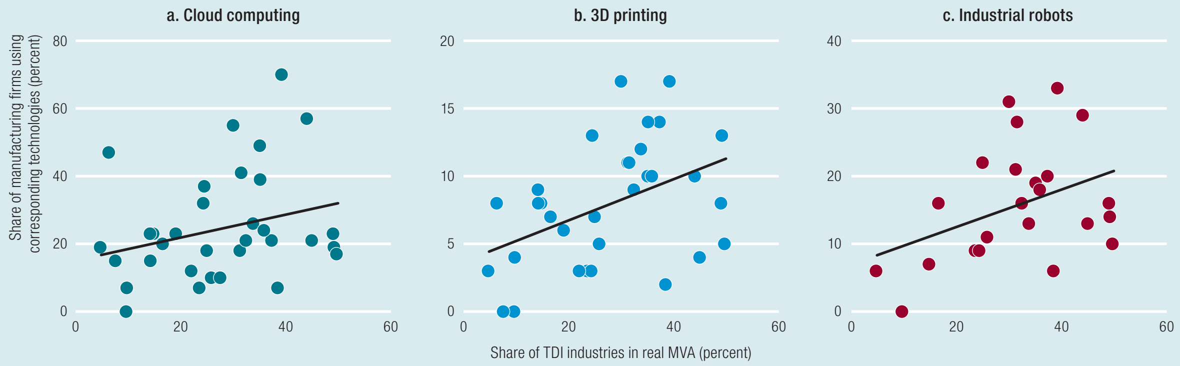
industries with the highest rate of adoption of new technologies. The computer and machinery industry and the transport equipment industry, with medium-high and high levels of both technology and digital intensity, can be regarded as technology- and digital-intensive (TDI) industries (bottom right quadrant). Sectors with low and medium-low technology and digital intensity have low rates of adoption of new technologies, except for the use of industrial robots in basic metals and fabricated metals (upper left quadrant). The other industries fall in between.[2]

Countries with a higher share of TDI industries adopt more ADP technologies

The productive structure of countries has a key role in determining the diffusion of ADP technologies (Figure 2.2). Countries with a higher share of TDI industries tend to have higher rates of adoption of key ADP technologies, indicating the importance of

TDI industries are the main bases for the development, learning and use of the new technologies

Figure 2.2
The adoption of key ADP technologies in manufacturing is positively associated with the share of TDI industries in MVA



Note: TDI is technology- and digital-intensive. MVA is manufacturing value added. All values are for 35 European economies in 2018 in real value added in constant $ 2010. The scatter plots show the average diffusion of each technology in the manufacturing sector against the share of TDI industries in real MVA.
Source: UNIDO elaboration based on Eurostat (2019) and the INDSTAT2 ISIC, Rev. 3. database (UNIDO 2019e).

developing these industries to promote the diffusion of ADP technologies in countries.

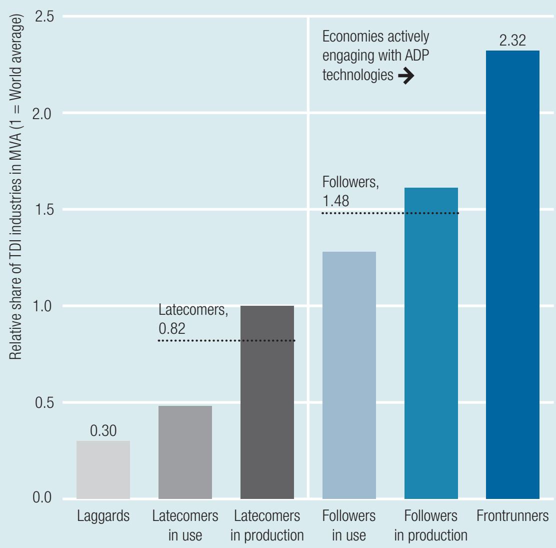
Frontrunners and followers have a larger share of TDI industries

The share of TDI industries in manufacturing value added (MVA) is related not only to the rate of adoption of ADP technologies in advanced economies, but also to the depth of engagement with these technologies around the world. Economies actively engaging with ADP technologies (frontrunners and followers) tend to have a much larger share of TDI industries, on average, than the world average share (Figure 2.3). The opposite happens in the latecomer and laggard economies. TDI industries are the main bases for the development, learning and use of the new technologies. Having a larger share of TDI industries enables countries to accumulate experience and deepen their engagement with these technologies. Thus, a county's industrial structure also matters for ADP technological advancement.

The positive relationship also holds within economies of similar income

Results are similar when the sample is split into country income groups. For each income category, economies more active in these technologies (frontrunners and followers) tend to have an above-average share of TDI industries and in all cases have a much larger share than latecomer and laggard economies in the same income category (Figure 2.4). These findings confirm that TDI

Figure 2.3
Economies actively engaging with ADP technologies tend to have a much larger share of TDI industries in MVA



Note: ADP is advanced digital production. TDI is technology- and digital-intensive. MVA is manufacturing value added. All values are for 2017 or the closest year and are in current $. The analysis includes 109 economies, 49 of which are actively engaged with ADP technologies. See Annex A.1 for the classification of economies by their level of engagement with ADP technologies.
Source: UNIDO elaboration based on Foster-McGregor et al. (2019) dataset derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018) and BACI International Trade Database (Gaulier and Zignago 2010) and on the INDSTAT2 ISIC, Rev. 3. database (UNIDO 2019e).

> **“TDI industries are crucial for a deeper engagement with the new technologies**

industries are crucial for a deeper engagement with the new technologies, moving countries from latecomers to followers and to more established exporters and innovators. South Africa, a follower country, is trying to transform a TDI industry using ADP technologies (Box 2.1).

Changing patterns of manufacturing development

How does adopting ADP technologies affect industries' performance?

TDI industries have higher rates of adopting ADP technologies and have had a key role in their use, export and innovation. But what about TDI industries' performance in MVA and employment growth? If adopting the ADP technologies brings a competitive premium, recent changes in manufacturing structure should favour TDI industries. ADP technologies took off around 2005 (Chapter 1). So, it is worth investigating how the patterns of structural change evolved before and after the takeoff.

Shares of real MVA

TDI industries' share in MVA increased after ADP technology takeoff

Figure 2.5 shows changes in average shares of each industry (the 10 industries in Table 2.1) before ADP technology takeoff (1991–2004) and after takeoff (2005–2016) for the whole sample (panel a) and for the subsample of economies actively engaging with ADP technologies (panel b). The two TDI industries had the largest increase in their shares of total MVA after takeoff of ADP technologies (shown in green in Figure 2.5). The chemicals and rubber and plastics industries also gained MVA shares. The other six industries either lost shares (most noticeably textiles and refined petroleum) or remained unchanged (food).

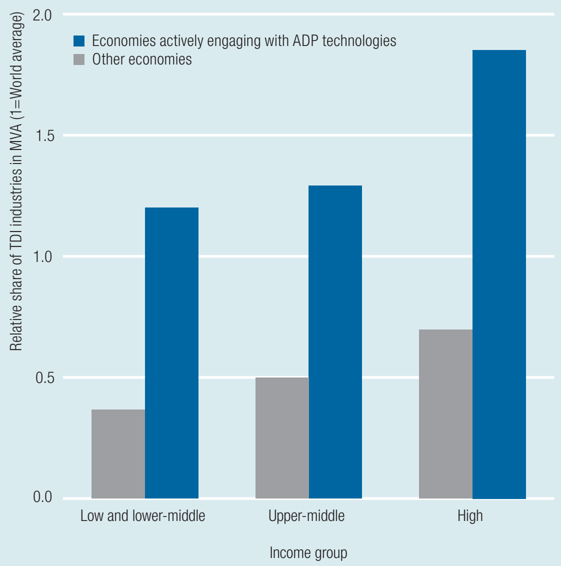
Frontrunners and followers have comparative advantages in TDI industries

Economies actively engaging with ADP technologies have similar patterns of change in the MVA shares of manufacturing industries (see panel b in Figure 2.5). What distinguishes these economies from the rest are the high increases in the MVA shares of TDI industries since 2005. Frontrunners and followers possess clear comparative advantages in these industries and thus have been changing their manufacturing structures to favour these industries much faster than other economies.

As countries get richer, TDI industries increase in importance

The picture changes, however, when country income levels are taken into account. The patterns distinguish between low-technology industries (as illustrated by food and textiles) and TDI industries. Low-technology industries have a negative slope, while TDI industries have a positive slope, reflecting that low-technology industries

Figure 2.4
Within country income groups, economies actively engaging with ADP technologies also tend to have a much larger share of TDI industries in MVA



Note: ADP is advanced digital production. TDI is technology- and digital-intensive. MVA is manufacturing value added. All values are for 2017 or the closest year and are in current $. The analysis includes 109 economies, 49 of which are actively engaged with ADP technologies, classified according to World Bank's income group definitions for 2017: 31 low and lower-middle income economies (of which 4 are active); 31 upper-middle income economies (of which 13 are active); and 47 high income economies (of which 32 are active). See Annex A.1 for the classification of economies by their level of engagement with ADP technologies.
Source: UNIDO elaboration based on dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018) and BACI International Trade Database (Gaulier and Zignago 2010) and on the INDSTAT2 ISIC, Rev. 3. database (UNIDO 2019e).

Firms that have adopted the predictive maintenance system have a competitive edge

Box 2.1

Fostering competitiveness through ADP technologies in South African machinery, equipment and electronics industry

South Africa, classified as a follower in the use of advanced digital production (ADP) technologies, has a strong industrial base for the machinery, equipment and electronics industry, a technology- and digital-intensive industry. With extensive backward linkages through its value chain, the industry has generated 250,000 jobs, making it the largest source of formal employment in the country.

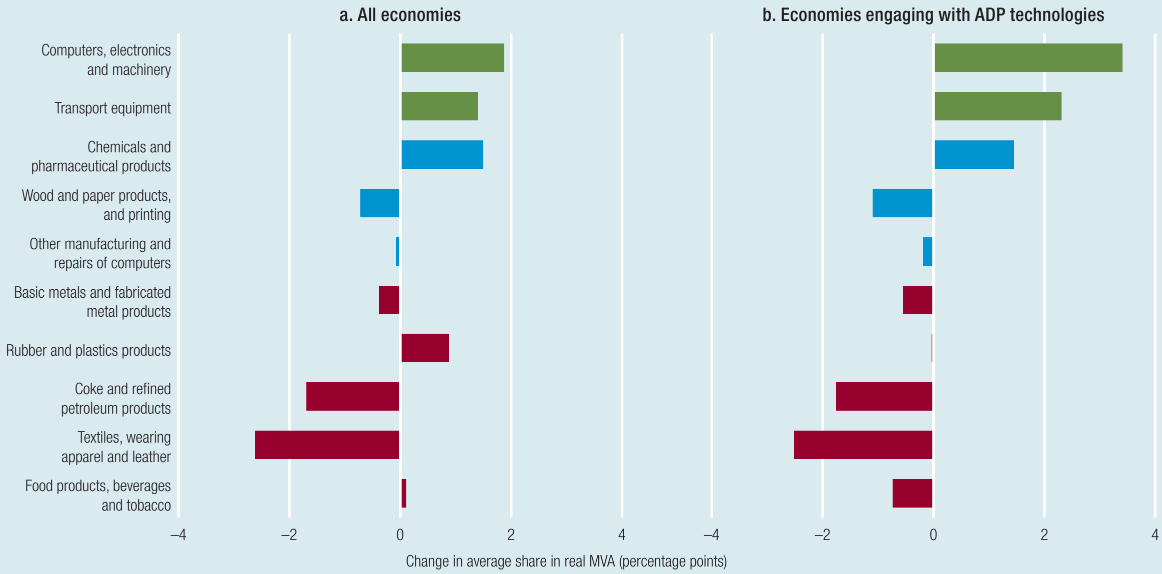
But the industry is becoming less competitive due to weak production skills and digital infrastructure, poor access to finance and high energy costs. Firms that have met such challenges have continuously upgraded their capabilities and invested in the latest technologies. For example, firms that have adopted the predictive maintenance and monitoring system—which uses a combination of sensors, big data, cloud computing, data analytics, Internet of Things and artificial intelligence—have a competitive edge. The technology allows leading producers to reduce costs by preventing unplanned downtime, monitoring wear rates, suggesting design improvements and reducing manufacturing waste. Predictive maintenance capabilities are important for winning new business and growing because after-market revenues can be 13–15 times bigger than the initial capital cost and installation.

To enable such capabilities to be diffused to all firms in the industry, not just the leaders, South Africa needs to remove constraints, such as high cost and limited bandwidth, skill shortages in information technology and data analysis, weak innovation system, and limited linkages with and between suppliers, universities and research centres.

Source: Kaziboni et al. 2019.

Figure 2.5

The average share of TDI industries increased after 2005, especially for economies actively engaging with ADP technologies



Note: ADP is advanced digital production. MVA is manufacturing value added. The figure shows the change in the average share in real MVA in constant $ 2010 between 1990–2004 and 2005–2017. 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 both. Red = industries that are intensive on neither digitalization nor technology. Panel b includes only frontrunner and follower economies, as defined in Chapter 1. See Annex A.1 for the classification of economies by their level of engagement with ADP technologies and Table 1.1 for the description and criteria used in the classification.

Source: UNIDO elaboration based on the INDSTAT2 ISIC, Rev. 3. database (UNIDO 2019e) with some data gaps filled using UNIDO (2012, 2019f), the World Input-Output Database (Timmer et al. 2015) and Los et al. (2015).

> **Low-technology industries decline in importance as countries get richer, while TDI industries increase in importance**

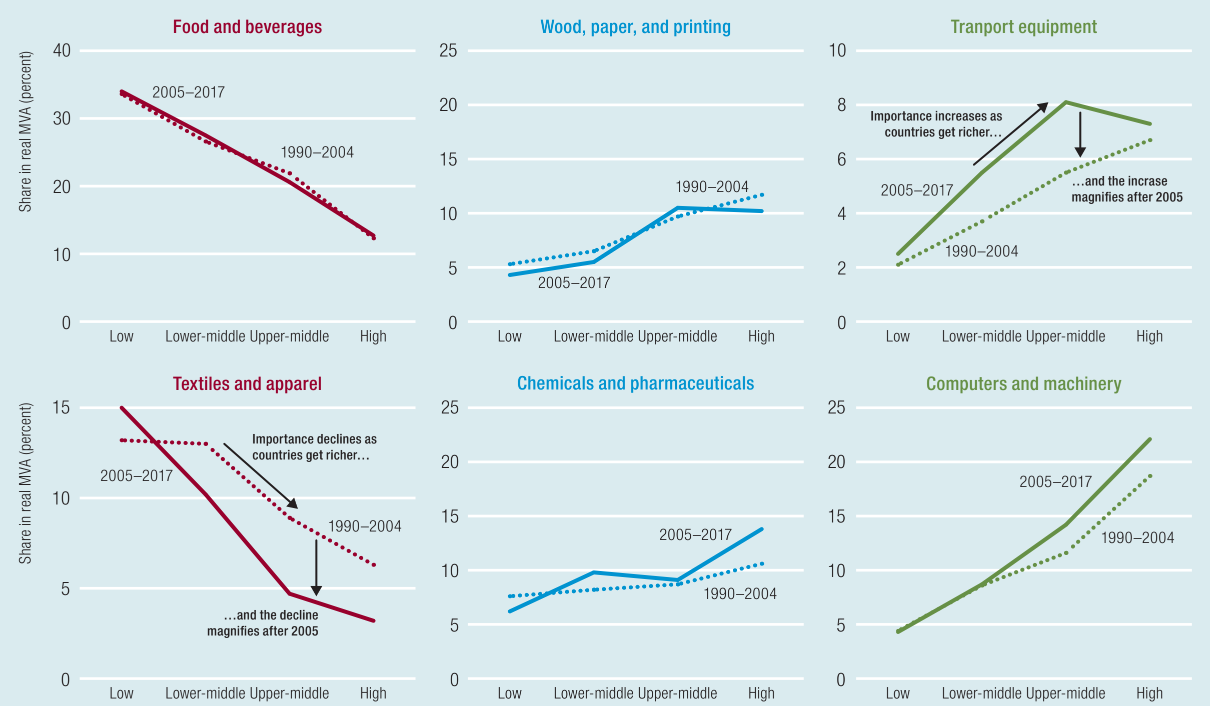
decline in importance as countries get richer, while TDI industries increase in importance (Figure 2.6).

The importance of TDI industries increased after 2005
This pattern was intensified in the most recent period (2005–2017), as low-technology industries (especially textiles and apparel) became less important and TDI industries more important. These changes are especially prominent among upper-middle and high income economies, indicating that both country and time factors affected the importance of TDI industries.

Drivers of real MVA growth: Employment and productivity

TDI industries grew in both employment and productivity
TDI industries, the main adopters of ADP technologies, grew faster than other manufacturing industries, as evidenced by their more rapid growth in MVA (Figure 2.7 panel a). They achieved that growth by increasing both employment and productivity (Figure 2.7 panels b and c). While rapid productivity growth is expected for TDI industries, the simultaneous growth in employment is important for inclusiveness. Before 2005 and the surge in ADP technologies, productivity growth in the transport equipment industry and the computer and machinery industry came at the expense of employment. So, the industries' MVA expanded at a slower rate than their productivity growth. After 2005, the two industries had fast productivity growth, but MVA expanded even faster, allowing for the simultaneous growth of labour productivity and employment. This expansion of employment made the growth more inclusive. It is likely that adopting ADP technologies helped these TDI industries produce more attractive products than before, resulting in higher demand and more inclusive growth.

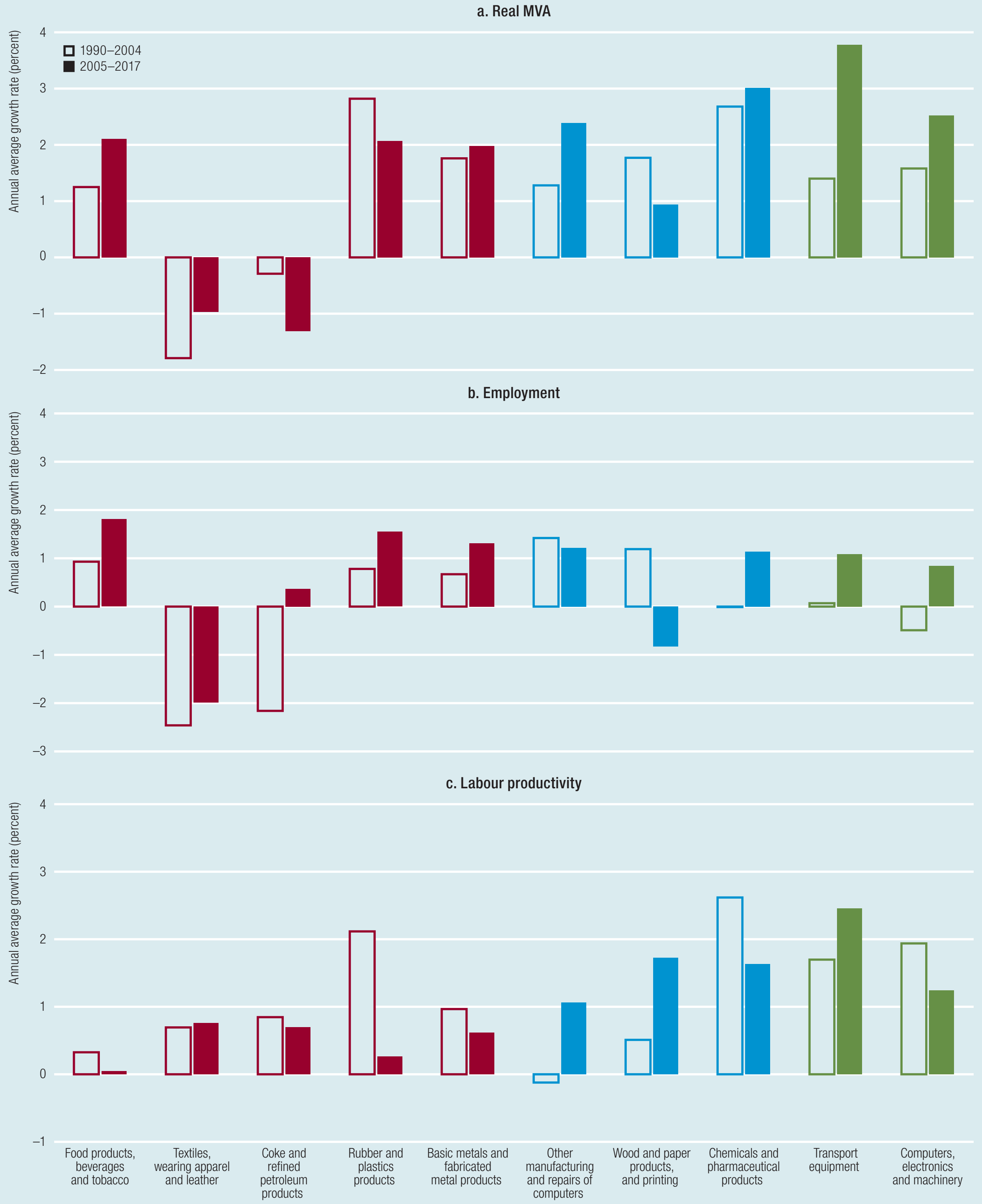
Figure 2.6
Shifts in the patterns of structural change before and after 2005 for selected industries by country income group



Note: Real MVA is real manufacturing value added in constant $ 2010. Income levels are low, lower-middle, upper-middle and high, as defined by the World Bank for the year 2005, the mid-point of the complete range considered. The analysis considers average real MVA shares for 86 economies with available data. The colours of the figures 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 both. Red = industries that are intensive on neither digitalization nor technology.
Source: UNIDO elaboration based on the INDSTAT2 ISIC, Rev. 3. database (UNIDO 2019e) with some data gaps filled using UNIDO (2012, 2019f), the World Input-Output Database (Timmer et al. 2015) and Los et al. (2015).

TDI industries grew faster than other manufacturing industries

Figure 2.7
Real MVA growth and its drivers: Employment and productivity



Note: MVA is manufacturing value added. The analysis includes 86 economies. Productivity is calculated as real MVA (in constant $ 2010) per number of workers. 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 both. Red = industries that are intensive on neither digitalization nor technology.
Source: UNIDO elaboration based on the INDSTAT2 ISIC, Rev. 3. database (UNIDO 2019e) with some data gaps filled using UNIDO (2012, 2019f), the World Input-Output Database (Timmer et al. 2015) and Los et al. (2015).

> **Active engagement with ADP technologies requires increasing support from knowledge-intensive services**

The takeoff of ADP technologies after 2005 favoured TDI industries

The evidence in this section demonstrates that the period since the takeoff of ADP technologies was more favourable for manufacturing development in general and TDI industries in particular than the period before that. Higher productivity was an important contributor to the superior growth since 2005, and expanding employment opportunities made the growth more inclusive.

Blurring boundaries between manufacturing and services

ADP technologies need support from the services sector

Changes in technologies and business opportunities shift production processes. Industrial evolution not only shapes the way things are produced within an industry but also transforms industrial organization —how industries are linked in value chains across sectors to produce final manufactured products. Active engagement with ADP technologies requires increasing support from knowledge-intensive computer and related services, research and development services and other business services.

KIBS support manufacturing

Knowledge-intensive business services (KIBS)[3] are important to innovation and as carriers of new knowledge in an economy.[4] They are mainly intermediate services (sold to other sectors rather than to final consumers), and through these linkages, they diffuse innovations to downstream industries (Berardino and Onesti 2018, Francois et al. 2015). As a result, their use in production helps manufacturing industries gain knowledge and skills (Barney 1991).

The interaction between manufacturing and KIBS improves productivity, competitiveness, and the quality of goods

Through this role as carriers of knowledge and innovation, increased use of KIBS in manufacturing enhances a country's productivity growth and its competitiveness (see Chapter 1). Product-embodied technology can improve the quality and competitiveness of downstream goods (Dietzenbacher and Los 2002). Supporting the emergence of these interactions between manufacturing and services is important for reducing productivity gaps between follower and leading economies. Box 2.2 shows how a firm in a developing country got a foothold in KIBS to provide design services as part of ADP solutions for manufacturing production.

Do economies engaging with ADP technologies have more integrations of KIBS with manufacturing?

Examining the integration of KIBS with manufacturing before and after 2005 should reveal whether economies engaging more actively with ADP technologies tend to show stronger KIBS integration in manufacturing and whether there are specific sectoral patterns in these interactions.

Changing trends in integration of KIBS with manufacturing

The contribution of KIBS to the value added generated by manufacturing is higher in rich economies

Figure 2.8 shows the average share of KIBS in the total value added generated by manufacturing industries in the two periods considered (1995–2004 and 2005–2015), by country income groups. The share of KIBS in MVA is higher in higher income country groups, indicating the importance of knowledge-intensive inputs for the kinds of manufacturing activities undertaken by high-income economies.

The contribution of KIBS to manufacturing has increased since 2005

KIBS are related not only to country income levels. The weight of KIBS in manufacturing production has also increased across country income groups since 2005, particularly in upper-middle and high income economies. If this trend continues, developing countries cannot simply strive to reach the current production structure of a higher income country by increasing

> **TDI industries tend to have an above average share of integration with KIBS**

Box 2.2

Entering global manufacturing through the provision of knowledge-intensive services

AEDesign, a diversified engineering company established in 2002 in Pakistan, provides a wide range of knowledge-intensive business services to its clients in the manufacturing sector. Services include concept design, detailed design, computer-aided design, embedded system design and electronic circuit design. It offers clients' flexibility and access to specialized skills while reducing their development time and costs.

From its early days, AEDesign focused on research and development to serve the manufacturing sector. Every project was considered a learning opportunity to enhance the skills and capabilities of the engineering team. By providing a compensation package 10–50 percent above the rate for equivalent positions in the market, and investing in training and team building, it assembled a strong team of 65 engineers.

Having developed the necessary technological competence and core engineering team by 2010, AEDesign established a subsidiary in Germany, a global frontrunner in advanced digital production (ADP) technologies, to access business and learning opportunities unavailable at home. Building on its initial engineering expertise in the automotive industry, AEDesign gradually expanded its business to meet local needs and offer ADP technology solutions to Pakistani industries that had a comparative advantage.

For example, in textiles, a major industry in Pakistan, thread breakage during spinning is common. Current practices are based on human observation to detect and then rectify the problem. AEDesign is developing a solution based on image recognition, which would immediately identify thread breakage and raise a service request.

With a subsidiary in Germany integrated in a global supply chain of ADP technologies, AEDesign keeps abreast of new business and technological developments in frontrunner economies. It is also developing a niche in the home country where demand for these types of solutions is growing.

Source: UNIDO elaboration.

the share of KIBS from 4.3 percent to 7.5 percent (the share in upper-middle income economies) and to 9.7 percent (high income economies). They probably need to aim for higher knowledge intensity in production than in the current advanced economies.

KIBS integration to manufacturing is greater in economies actively engaged in ADP technologies

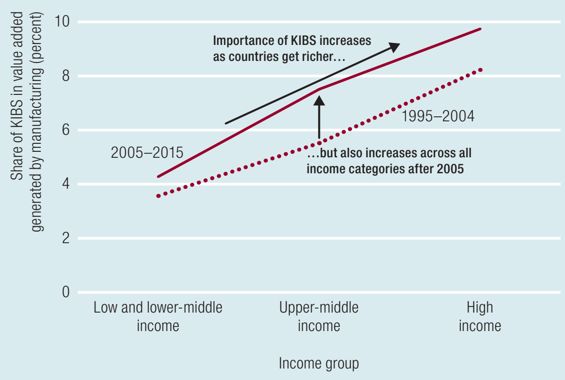
Across all country income groups, the integration of KIBS in manufacturing is greater in economies that are actively engaging with ADP technologies (Figure 2.9). As countries move to a higher level of engagement in developing and deploying ADP technologies, with greater involvement in TDI industries, KIBS need to play an increasing role in manufacturing.

TDI industries have an above-average share of integration with KIBS

Similar to the trends in TDI and ADP technologies, KIBS integration into manufacturing in recent years indicates that TDI industries tend to have an above-average share of integration with KIBS across all country income groups (Figure 2.10). That implies a connection between engagement with ADP technologies, the structure of industry and the role of KIBS in manufacturing production.

Figure 2.8

Manufacturing increasingly relies on KIBS across all incomes



Note: KIBS is knowledge-intensive business services. Manufacturing value added is in current $. Multiregional input–output techniques are used to estimate the weight of KIBS in the total value added created by the final demand for manufacturing goods. This analysis includes 63 economies, which are classified according to World Bank income group definitions for 2005, the mid-point of the complete range considered: 30 low and middle income economies (of which 9 are active) and 33 high income economies (of which 24 are active).

Source: UNIDO elaboration based on Inter-Country Input-Output (ICIO) Tables (OECD, 2016, 2018b).

> **Frontrunners and followers have a much higher share of TDI industries in their MVA**

Differences in industrial structure at different levels of ADP engagement

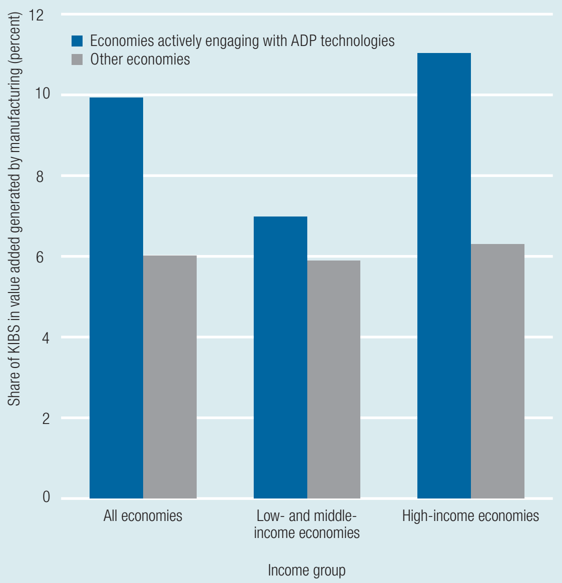
In ADP technology frontrunner and follower economies, the share of TDI industries in MVA is high

The superior performance of frontrunners and followers did not come from a larger engagement with ADP technologies than latecomers and laggards at the same manufacturing activities. Rather, frontrunners and followers have a much higher share of TDI industries (computer and machinery industry and transport equipment industry) in their MVA. TDI industries rose more rapidly in importance after the takeoff of ADP technologies in 2005. The rate of the adoption of ADP technologies is much higher in TDI industries than in other manufacturing industries, and their MVA growth is also higher. Such superior performance is strongly driven by productivity growth, in turn possibly stimulated by demand and supply growth.

ADP technologies foster productivity and employment growth that make development inclusive

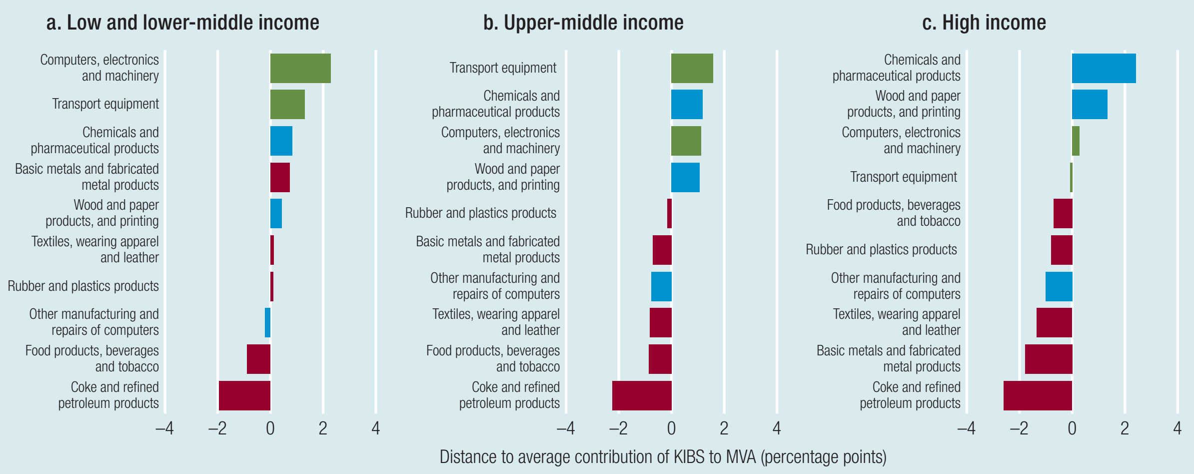
However, the story of TDI industry development is not about the substitution of new technologies for labour. It

Figure 2.9
Manufacturing industries in economies actively engaging with ADP technologies are more integrated with KIBS at all country group income levels



Note: KIBS is knowledge-intensive business services. ADP is advanced digital production. Values are averages for the period 2005–2015. Manufacturing value added is in current $. The analysis includes 63 economies, which are classified according to World Bank 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). See Annex A.1 for the classification of economies by their level of engagement with ADP technologies.
Source: UNIDO elaboration based on Inter-Country Input-Output (ICIO) Tables (OECD, 2016, 2018b).

Figure 2.10
KIBS are more integrated with TDI industries than average, especially in developing countries



Note: MVA is manufacturing value added is in current $. KIBS is knowledge-intensive business services. Average values for the period 2005–2015. This 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). 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 both. Red = industries that are intensive on neither digitalization nor technology.
Source: UNIDO elaboration based on Inter-Country Input-Output (ICIO) Tables (OECD, 2016, 2018b).

ADP technologies could shift the distribution of value added and employment across sectors

is more about the contribution of ADP technologies to the competitiveness and expansion of these industries, which made the development process inclusive through the growth of both productivity and employment.

Frontrunner and follower economies have a high share of KIBS in manufacturing

Not only are the industrial structures (what to produce) different between frontrunners and followers and latecomers and laggards, but their production processes (how to produce) also differ. Frontrunners and followers have a higher level of KIBS inputs—including computer and related services and research and development services—into their manufacturing production. That higher contribution of KIBS seems to be a defining feature of frontrunners and followers relative to the rest.

ADP technologies and the "skills of the future": Risks of digitalization

ADP technologies could change manufacturing, employment, and value added across industries and sectors

With rapid development and deployment of ADP technologies, the prospects for employment and value added growth have changed in each industry. In the future, ADP technologies could shift not only the relative importance of industries and manufacturing processes but also the distribution of value added and employment across sectors.

Effects of ADP technologies on the labour market are unclear

Despite the great potential of ADP technologies for productivity growth and competitiveness, some caution and moderation of expectations are warranted. The main concerns are associated with changes in the labour market and impacts on employment in the manufacturing sector.

Technological advances are increasing machines' ability to substitute for labour

In the debate on ADP technologies and the future of work, one side focuses on the labour-saving potential of ADP technologies. This idea is reinforced by the fact that these technologies have improved the performance of machines in fields that require nonroutine cognitive skills, expanding the set of activities that machines can perform effectively, such as natural language processing or image, video and speech recognition. Moreover, advances in the dexterity of robots have allowed them to perform more nonroutine manual tasks (Brynjolfsson and McAfee 2014, Frey and Osborne 2017, Graetz and Michaels 2018). These changes could make it easier to substitute machines for human workers and reshape labour markets.

But technological advances may also create new kinds of occupations and so create employment

The other side notes that the effect of new technologies may also be transformative by complementing the work of humans, boosting productivity by facilitating the execution of some tasks or by enabling operations and processes that humans could not perform unaided. There is thus optimism for new job creation through the diffusion of ADP technologies, driven by new occupations (software developers, data analysts) and by employment creation through increased industrial linkages.

Analytical, technology-related and soft skills will be needed in jobs created by ADP technologies

Whatever the net employment impact of these different forces, what seems clear is that technological change is not neutral with respect to the profile of job skills demanded. Technological change tends to favour skills that are complementary to the new technology (Acemoglu 2002, Rodrik 2018). Even if debate on the set of skills that will be required to perform with ADP technologies is still open, the needed skills are expected to be biased towards three broad categories: analytical, technology-related and soft skills (Kupfer et al. 2019). As the jobs created by ADP technologies are likely to be more demanding of new and technical skills, as well as of analytic and cognitive abilities, mastering the "skills of the future" will provide the best safeguard against displacement by technology. That presents major challenges to workers in developing economies, who must

> **There is still no clear-cut evidence on whether ADP technologies will make some occupations redundant**

adapt to these changes in order to take advantage of the opportunities offered by ADP technologies (Box 2.3).

More study is needed on the employment effects of ADP technologies for developing countries and for women

Even with lively policy and academic debates, there is still no clear-cut evidence on whether ADP technologies in manufacturing will really make some occupations redundant or whether, instead, they will change the content of jobs without necessarily replacing human workers. ADP technologies might also create occupations that never existed before. Most studies focus on advanced economies, and so the evidence on the effects on labour markets in developing countries is scarce and less conclusive. Nor has it been possible to assess whether gains or losses will be greater among women than among men, because the evidence on gender-specific effects on employment is even rarer and limited to advanced economies (Brussevich et al. 2018, Sorgner 2019). Filling this information gap is crucial for developing a policy agenda to increase women's equitable participation in the industrial workforce and in the development of technologies, which is fundamental to promoting inclusive and sustainable industrial development (ISID) (UNIDO 2019d).

Gender differences in the risk of digitalization

How will ADP technologies affect men and women's jobs in developing countries?

To begin to fill this gap, this section offers evidence from new empirical studies of the potential differential

Box 2.3
Skills of the future for manufacturing

Smart factories represent the latest advance in the application of advanced digital production technologies at the plant level (Chapter 1). In smart factories, workers, products, equipment and machinery are part of an intelligent system in which components interact, exchange information, take decisions and implement actions through digital networks of sensors powered by real-time data analytics, machine learning and intelligent algorithms. Smart factories also use augmented and virtual reality to simulate real-world environments and optimize manufacturing and maintenance processes before they are carried out. This overlapping of physical and digital infrastructure—the cyber-physical system—allows manufacturing operations to occur faster and more efficiently and to produce a new generation of smart products of greater value added and serviceability for customers.

Due to the intensive use of data in real-time decision-making and the increased connectivity, a different set of skills is needed to operate a smart factory than a traditional plant. Arçelik, a Turkish multinational company with decades of experience in white goods production, reports that one of the most important challenges of current digital transformation is building the right set of skills to work in a smart factory environment.

Arçelik opened its first smart factory to produce washing machines in early 2019. As 90 percent of the tasks require digital competencies, employees need to have a complex set of technical and digital skills in automation, coding, data management and analytics, network and data security, development of intelligent algorithms, integration of algorithms into physical production processes, and real-time decision-making based on data. These hard skills have to be matched with a set of advanced soft skills, such as problem solving and learning, teamwork, communication and negotiation. Soft skills are important for smart factory operations because the connectivity among all parts of the smart system—from suppliers; to customers, who can customize the products according to their preferences; to final products, which can communicate back to the manufacturer to improve performance and provide after-sale assistance—requires workers to coordinate with different actors, while serving as platform managers.

The move from traditional blue-collar mechanical and repetitive activities to digital-manager type duties implies more negotiating and coordinating tasks, and at the same time frees workers from heavy and hazardous activities. In this regard, even though Arçelik already has gender policies in place to employ women in all functions, the reduction of more physically demanding tasks in smart factories could open up more opportunities for female workers. Besides looking for already qualified individuals when hiring, Arçelik also provides on-the-job training to reskill staff in the required set of abilities, also in collaboration with local higher education institutions.

Source: UNIDO elaboration.

“The risk of computerization varies widely across manufacturing sectors

impact that the adoption of ADP technologies might have on men’s and women’s jobs in the manufacturing sector of developing countries.[5]

Women concentrate in sectors with low technological intensity and low value added

The likelihood of the digitalization of jobs and the impact on male and female workers in 11 developing and transitioning economies was analysed based on the Skills Towards Employability and Productivity (STEP) program database.[6] The sample has similar numbers of women (52 percent) as men (48 percent) in the manufacturing sector, but women’s share (about 68 percent) is larger than men’s in the textiles and leather sector and in the wood, paper and printing sector (about 60 percent; Figure 2.11). This is in line with the gender distribution of employment by sector and occupation in the manufacturing sector of most developing economies, where women tend to concentrate in sectors with lower technological intensity and low value added and where lower labour costs represent a comparative advantage (UNIDO 2019d).

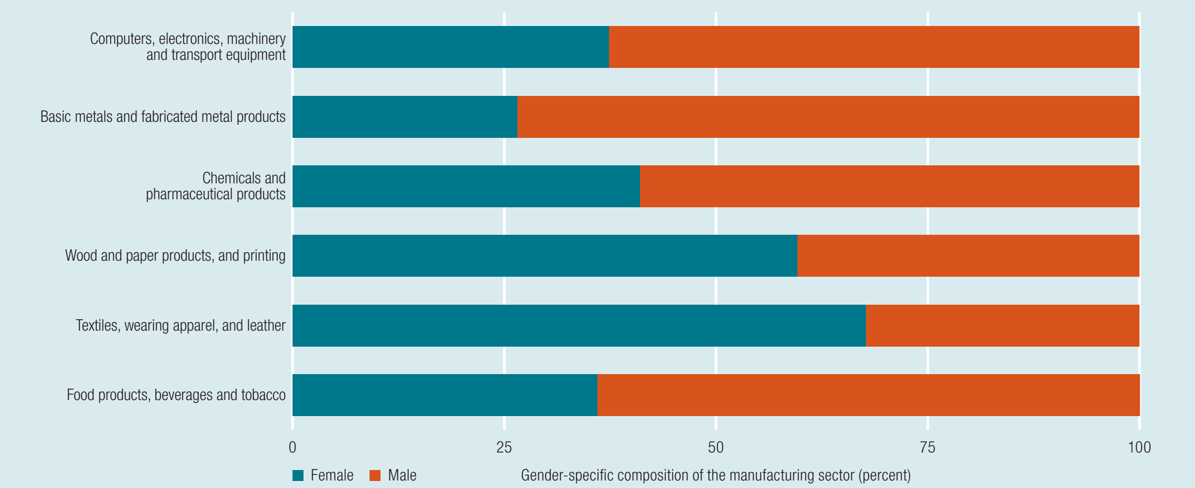
Using workers’ skills and competencies to study the risk of computerizing jobs

The probability of the computerization of jobs was used to measure the risk of digitalization, based on the approach in Frey and Osborne (2017).[7] A corrected measure of computerization is obtained for each individual worker by incorporating information on demographics, skills, education and workplace responsibilities from the STEP database. This allows investigating how workers’ skills and competencies are systematically related to the susceptibility of their occupations to digitalization, and how much these relationships differ between women and men.

Risks of computerization vary by sector and gender

Several findings stand out. First, the risk of computerization varies widely across manufacturing sectors (Figure 2.12). The risk of computerization is higher in food and textiles and lower in computers, electronics and vehicles. Second, gender differences are pronounced: the risk of computerization is on average about 2.9 percent higher for women in manufacturing. Female workers face a higher average computerization

Figure 2.11
Women constitute the largest share of workers in textile and wood industries



Note: Shares of male and female workers in each subcategory of manufacturing sector were calculated using country-specific sample weights provided in Skills Towards Employability and Productivity (STEP) program surveys. The analysis includes Armenia, Colombia, Georgia, Ghana, Kenya, Lao People’s Democratic Republic, North Macedonia, Sri Lanka, the Plurinational State of Bolivia, Ukraine and Viet Nam.
Source: UNIDO elaboration based on dataset by Sorgner (2019) derived from the STEP Skills Measurement Program (World Bank 2016).

> **“Women’s computerization risk is about 2–3 percentage points higher at each level of formal education**

risk when employed in food, beverages and tobacco, textiles and leather, and chemicals sectors. No statistically significant gender differences in computerization risk are observed in TDI industries—computers, electronics and vehicles.

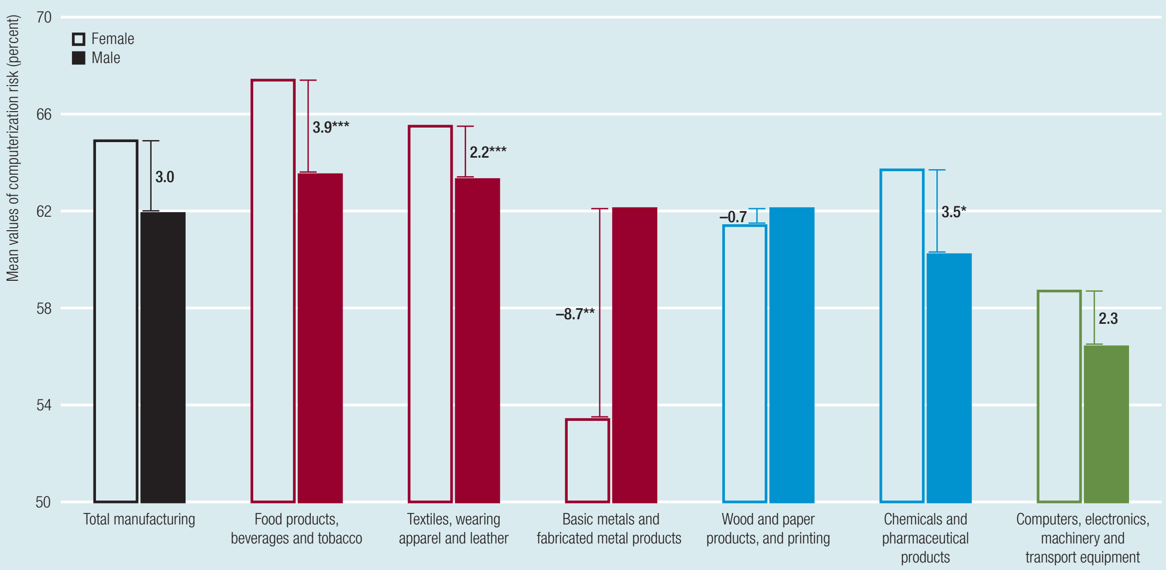
High-skilled jobs risk computerization less, but at all skill levels, women’s risk is higher than men’s

Third, in line with other empirical work (Brussevich et al. 2018, Sorgner et al. 2017), the risk of computerization declines with education, as workers in high-skilled jobs face lower probabilities of computerization than workers in low- and medium-skilled jobs (Figure 2.13). Still, women’s computerization risk is about 2–3 percentage points higher at each level of formal education. This finding suggests that the higher job computerization risk of female workers cannot be entirely explained by gender differences in education and that other gaps may be at play.

Jobs requiring analytical and ICT skills are less vulnerable to digitalization but show major gender gaps

Strong differences in skill endowments seem to be the main factor behind the differences in computerization probabilities observed in Figure 2.12: in manufacturing jobs, women score significantly lower than men, on average, in the skills that are particularly valuable for working with ADP technologies—the “skills of the future,” such as analytical and information and communications technology (ICT) skills (Figure 2.14). While routine manual skills can easily be automated, the “skills of the future” are less vulnerable to digitalization and are more likely to be complemented by than to be replaced by new technologies, shielding workers from potential job destruction from digitalization and enabling them to benefit from opportunities the emerge from transformative digitalization and the creation of new tasks. (Table 2.2 describes the skill categories.)

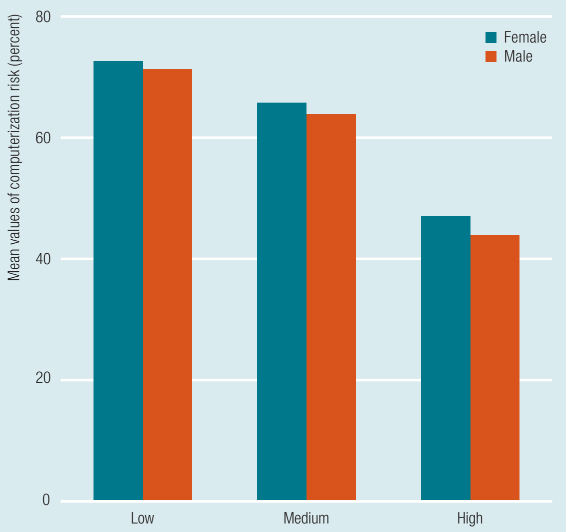
Figure 2.12
Female workers are more likely to face a higher computerization risk than men if they are employed in food, textiles and chemicals



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 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).

> **Labour markets increasingly reward social skills**

Figure 2.13
The risk of computerization declines with formal education for both male and female workers



Note: Computerization risk refers to the probability that an occupation will be computerized in the near future. The figure shows female–male differences in mean values of computerization risk by highest achieved educational level, measured according to the International Standard Classification of Education (ISCED 1997): low (ISCED 1 or less), middle (ISCED 2, 3, 4A, and 4B), and high (ISCED 5 and 6). The analysis includes Armenia, Colombia, Georgia, Ghana, Kenya, Lao People's Democratic Republic, North Macedonia, Sri Lanka, the Plurinational State of Bolivia, Ukraine and Viet Nam.
Source: UNIDO elaboration based on dataset by Sorgner (2019) derived from the Skills Towards Employability and Productivity (STEP) program (World Bank 2016).

Gender gaps are less pronounced in socio-emotional or soft skills

Thus, people whose job requires low analytical and ICT skills face a higher risk of their jobs being automated; this risk seems to be, on average, higher for women. To some extent, this higher risk is counterbalanced by the less pronounced gender gaps in soft skills.[8] The empirical evidence supports the argument that labour markets increasingly reward social skills and that the share of soft-skill-intensive occupations will grow by the next decade (see Chapter 3). Having an advantage in these skills could thus narrow gender gaps in the future.

Women's access to high-quality jobs in manufacturing is limited

Differences in computerization risk may also be affected by the gender allocation of tasks and by gender-diverse occupational choices. Employers' stereotypes and societal gender norms may be limiting women's access to good jobs and occupations, particularly when high-quality jobs are scarce (UNCTAD 2017). Women are less likely to choose an occupation in science, technology, engineering, or mathematics (STEM) and are underrepresented in managerial positions (Sorgner et al. 2017). In the sample, women hold fewer than 30 percent of managerial positions (Figure 2.15). And even in the same sector and occupation, women tend to conduct more routine, codifiable tasks that require less abstract thinking than their male counterparts, placing women's jobs at higher risk of loss to computerization than men's jobs.

More female workers are at high risk of computerization

What do these different computerization risks mean for actual employment risk? Using a probability of computerization higher than 70 percent as the threshold for high risk of job displacement means that about 30 percent of workers in manufacturing could be severely affected, on average. The share at risk varies by gender and sector, however (Figure 2.16).[9] The share of female workers at risk is particularly high in food and beverages (51 percent of female workers), though women do not represent the majority of the workers in this sector. The opposite holds for wood and paper, where, despite constituting 60 percent of the labour force, only 7 percent of female workers face a high risk of displacement by computerization.

The risk of computerization is lowest in TDI industries —for both men and women

The share of workers strongly affected by the probability of computerization is lowest in computers, electronics, and vehicles for both men (9.2 percent) and women (3.6 percent), suggesting that jobs in these sectors rely more on the new skills that are complementary to computerization and thus are less susceptible to displacement. This result confirms the importance of TDI industries for inclusive development. As discussed earlier in the chapter, TDI industries are the main adopters of ADP technologies, and they have managed to simultaneously increase both productivity and employment in recent years.

> **“Jobs in TDI industries are less susceptible to displacement**

Figure 2.14

Women score lower than men on skills that may protect jobs from loss through computerization in manufacturing

Note: The vertical axis shows the female–male differences in mean values of scores associated with each skill. The variables measuring skills have been standardized to make the scales comparable. The analysis includes Armenia, Colombia, Georgia, Ghana, Kenya, Lao People's Democratic Republic, North Macedonia, Sri Lanka, the Plurinational State of Bolivia, Ukraine and Viet Nam. See UNIDO background paper prepared by Sorgner (2019) for a detailed description of the classification of the skills measured in the STEP program.

Source: UNIDO elaboration based on the background paper prepared by Sorgner (2019) derived from the STEP Skills Measuremnt Program (World Bank 2016).

Table 2.2

Skills categories and corresponding measures in the Skills Towards Employability and Productivity program

Skill category	STEP measure
Analytical/cognitive	Reading, writing, numeracy, thinking for at least 30 minutes to do tasks, learning new things at work
Manual	Routine (physical demanding, repetitive tasks, operating machines, autonomy) and non-routine (driving vehicles, repair electronic equipment)
Interpersonal	Collaborating with co-workers, contacting clients, making presentations, supervising co-workers
Information and communications technologies	Computer use: intensity and complexity
Soft skills	Big Five dimensions of personality (openness to experience, conscientiousness, extraversion, agreeableness and emotional stability) and other socio-emotional skills (grit, hostile attribution bias, decision-making)

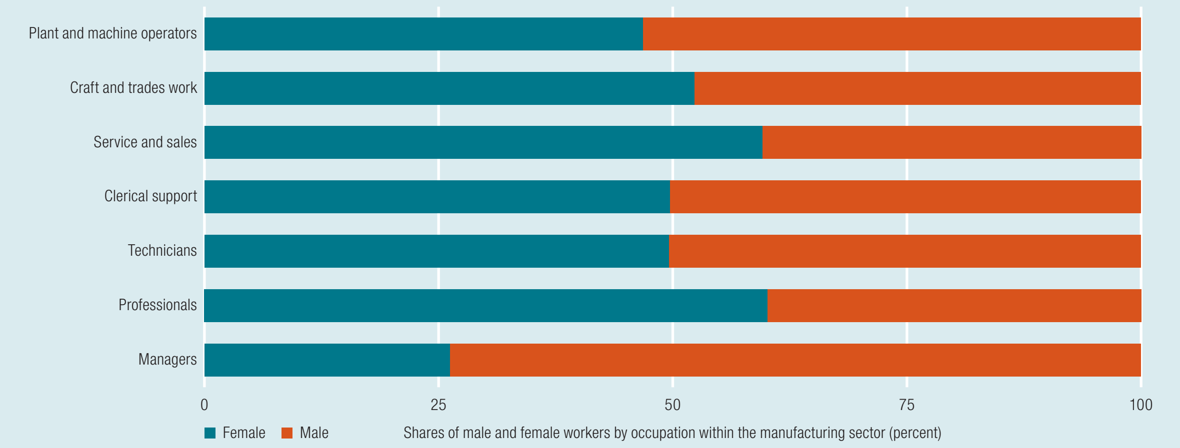
Source: UNIDO elaboration based on Sorgner (2019).

Computerizing jobs is only likely where it will be profitable

The risk of computerization may not turn into actual job losses, however, which means that the potential adverse employment effects of digitalization and automation in manufacturing may be overestimated (Brussevich et al. 2018, UNCTAD 2017). The risk of computerization reflects the technical feasibility of job substitution, but for this change to be realized requires the presence of conditions that make such substitutions economically profitable. That may not be the case in manufacturing sectors where labour compensation is low, such as textiles and apparel. Even if the jobs rank high on the

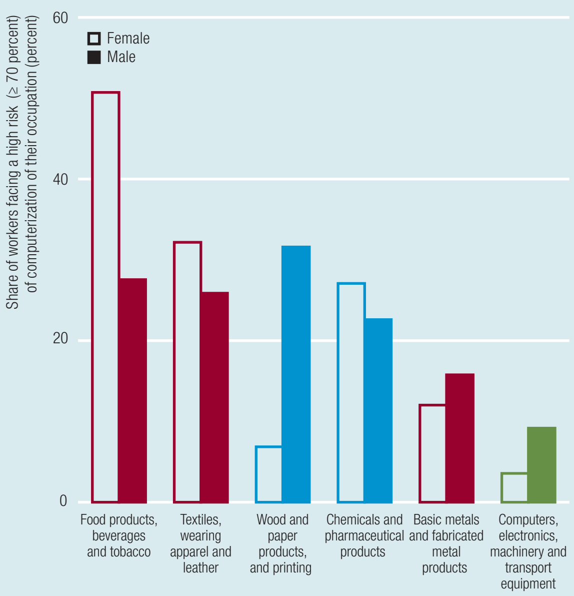
> **The potential adverse employment effects of digitalization may be overestimated**

Figure 2.15
Women are underrepresented in managerial position in manufacturing



Note: The shares of male and female workers by occupation within the manufacturing sector are weighted using country-specific sample weights provided in Skills Towards Employability and Productivity (STEP) program surveys. The analysis includes Armenia, Colombia, Georgia, Ghana, Kenya, Lao People's Democratic Republic, North Macedonia, Sri Lanka, the Plurinational State of Bolivia, Ukraine and Viet Nam.
Source: UNIDO elaboration based on dataset by Sorgner (2019) derived from the STEP Skills Measurement Program (World Bank 2016).

Figure 2.16
A larger proportion of the female workforce is at high risk of job displacement from computerization in food, beverages and tobacco



Note: The observations are weighted using country-specific sample weights provided in Skills Towards Employability and Productivity (STEP) program surveys. The analysis includes Armenia, Colombia, Georgia, Ghana, Kenya, Lao People's Democratic Republic, North Macedonia, Sri Lanka, the Plurinational State of Bolivia, 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 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).

technical feasibility of automating routine tasks, actual computerization is likely to remain limited. Indeed, TDI industries are the most likely to adopt ADP technologies but have the lowest risk of computerization of jobs in the developing economies analysed in this section. Jobs also adapt to major changes during large technological revolutions by altering the nature and content of tasks in favour of new skills. Thus, computerization can be transformative when new technologies complement human labour without replacing it, creating positive spillovers and new employment opportunities.

Policies to close gender gaps

The overall impact of ADP technologies on inclusiveness will depend on public policies

Fostering gender equality and gender empowerment in the changing landscape of work remains imperative. The overall impact of ADP technologies on gender equality and inclusiveness will ultimately depend on what policies are implemented (UNIDO 2019d).

Encouraging women in the labour force will fail if polices replicate gender segregation

A key policy challenge is how to offer women more and better job opportunities in manufacturing. The

> **The impact of ADP technologies on inclusiveness will ultimately depend on policies**

gains from encouraging women's participation in the labour force may be quickly eroded if industrial polices replicate gender segregation in the labour market and women continue to be overrepresented in occupations and tasks at high risk of loss through automation. An industrial strategy is needed that expands women's economic opportunities as part of the process of industrialization.

Promoting gender equality requires fostering women's participation in new sectors and occupations

Promoting gender equality within an agenda of ISID requires enabling women to participate more in new sectors and in roles where they are underrepresented and where technological change can complement human skills, as in leadership and managerial positions and in STEM occupations. As stereotypes and societal norms may constrain women's access to good jobs, policy efforts need to focus on altering those perceptions and encouraging companies to hire women and offer them gender-equal conditions (UNIDO 2019d).

Developing adequate skills for both female and male workers to meet future demand

Meeting the challenges of ADP technologies requires modernizing school curricula, including attention to soft skills, and promoting workforce training and lifelong learning to reduce skill-mismatches for a changing workplace. Attention to training and reskilling the existing labour force—for both male and female workers—must also be part of the policy debate about the future of work (see Chapter 4).

ADP technologies and inclusive industrialization: Direct, indirect and net effects of the use of industrial robots

How will industrial robots affect the economy directly and indirectly?

The previous section focused on the potential direct impact of computerization on the manufacturing sector, providing insights into the sorts of skills that could be automated in individual manufacturing industries. This section analyses the direct and indirect macro effects of technology—here industrial robots[10]—on employment in the overall economy. The indirect effects are based on both domestic and international linkages derived from intercountry input–output tables for both industrialized and emerging industrial economies.[11] Growth of value added in one sector can indirectly influence employment in another through backward or forward linkages. Using industrial robots in the manufacturing of computers, electronics and optics, for example, could result in productivity gains that translate into higher quality and less expensive products. In turn, these products are used in many other sectors, including services, which themselves do not use robots. These more efficient intermediate inputs can lead to productivity gains in the using sector that could eventually create new employment.

Growth in the stock of robots in manufacturing

Industrial robots have been operating for nearly two decades

Multipurpose industrial robots are expected to play a primary role in the manufacturing of the future, characterized by cyber-physical systems (CPS) and smart production. As seen in Chapter 1, robotics is just one component of the broader set of ADP technologies that is transforming manufacturing. However, industrial robots, having been in operation for nearly two decades in some countries, are the only technology whose impact on employment can already be assessed. It is too soon to assess the impact of newer technologies—such as artificial intelligence and big data analytics—for a large number of countries and in a comparable way.

By 2014, there were more than 1 million industrial robots, 175,000 in emerging industrial economies

Around half a million industrial robots were installed and used in industrialized economies in 2000. For the stocks of robots in other economies, data from the International Federation of Robotics Database begin

> **From 2000 to 2014, global investment in industrial robots doubled**

with 2005. From 2000 to 2014, global investment in industrial robots doubled, to more than 1 million robots in industrialized economies and 175,000 in emerging industrial economies (Figure 2.17).[12] The trend follows the patterns described in Chapter 1 for the growth of ADP technologies, confirming the take-off of ADP technologies around 2005.

Impact on employment

How to find the direct aggregate effect of robotization on employment

The direct effect that growth in the stock of industrial robots in one industry in one country would have on world employment depends on how much the growth in the stock of robots (average annual growth from 2000 to 2014) in a particular industry affected employment in that industry. To calculate the aggregate impact, all the direct effects by industry were added across countries (Figure 2.18).

And the indirect effect in customer and supplier industries

The indirect impacts were also calculated. Increased use of robots in an industry could affect employment in customer and supplier industries. For example, the industry using more robots might produce intermediate products of better quality and at cheaper prices for its customer industries, which in turn could increase competitiveness in those industries, enabling them to hire more workers to expand their businesses. The increase in the use of robots could also have an indirect impact on supplier industries if increased automation and changes in production processes translate into higher demand for certain materials and components. That could affect employment in supplier industries. The aggregate indirect effects of growth in the stock of robots is estimated by aggregating the impact on customer industries and supplier industries (see Figure 2.18). The impacts are aggregated separately for domestic and foreign customer and supplier industries.

Growth in the stocks of robots had a small and positive effect on employment growth

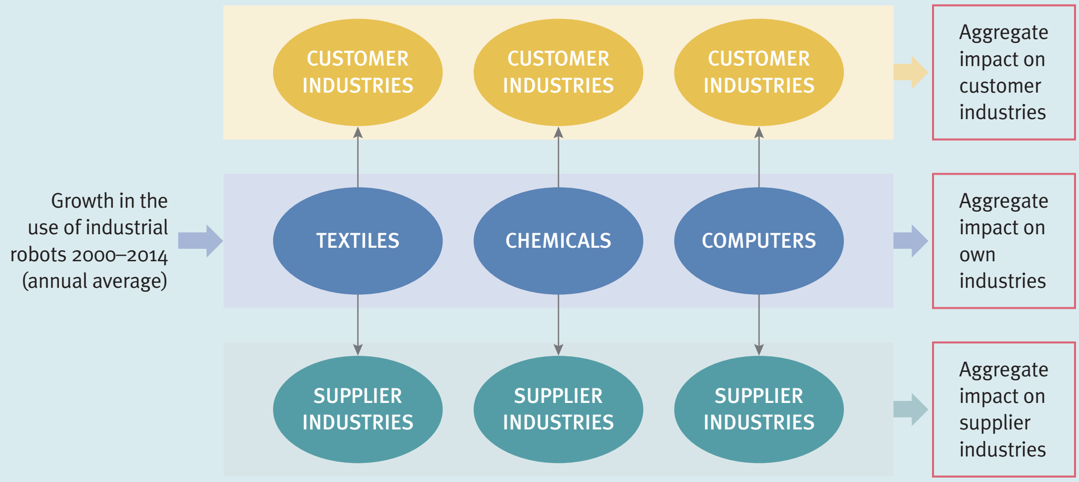
The annual growth in the stocks of robots had a positive but small effect on employment growth from 2000 to 2014 (Figure 2.19). For example, the average direct effect of the growth in the stock of robots across all economies and industries implies employment growth of about 0.14 percent a year. The positive direct effect is reinforced by domestic (0.18 percent) and international (0.06 percent) customer linkages. Supplier

Figure 2.17
The stock of industrial robots doubled between 2000 and 2014

Source: Ghodsi et al. (2019) based on International Federation of Robotics Statistical Department, World Robotics (IFR 2017).

> **The annual growth in the stocks of robots had a positive but small effect on employment growth from 2000 to 2014**

Figure 2.18
Aggregate impact of the increase in industrial robot use in individual industries on world employment



Source: UNIDO elaboration.

linkages were mixed, however, with a large negative domestic supplier effect (–0.3 percent) and a positive international supplier effect (0.24 percent). The overall employment effect is thus 0.32 percent a year.[13]

Employment growth occurred mostly in emerging industrial economies, not industrialized economies

The majority of job creation due to the world growth of robotics took place in emerging industrial economies, through international customer and supplier linkages (see Figure 2.19). In global value chains, the impact on the employment in international customer and supplier firms due to adoption of robots originated mainly from the growth of the stock of robots in industrialized economies. Those international customers and suppliers are mostly in emerging industrial economies. However, the net employment impact of the adoption of robots within emerging industrial economies is negligible. The industries that increased the use of robots generated employment in their own industries as well as in their domestic customer industries, but that employment gain was largely offset by the employment loss in domestic supplier industries (Figure 2.20). So for emerging industrial economies aiming at employment creation, the most reliable channel would be to insert their industries into global value chains as suppliers to foreign industries that are increasing their adoption of robots.

Manufacturing accounts for two-thirds of world employment growth attributable to robotization

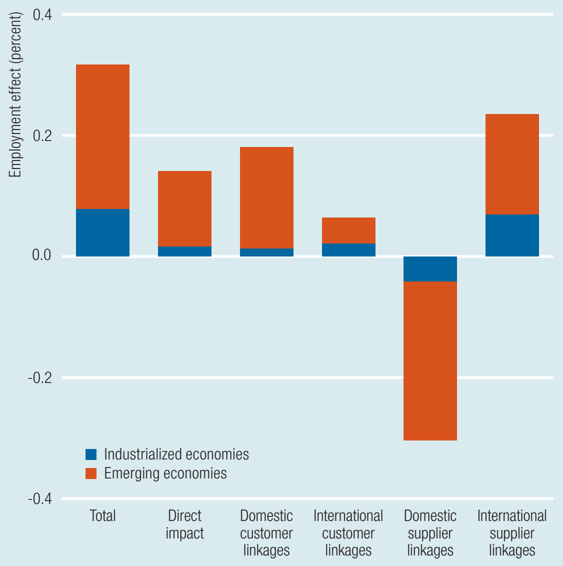
The adoption of robots in the manufacturing sector is the main driver of the economy-wide employment growth due to automation (Figures 2.21 and 2.22). Manufacturing accounts for two-thirds of the 0.32 percent growth in world employment attributable to the adoption of robots (see Figure 2.22). But the employment growth is not entirely in manufacturing (see Figure 2.21). The adoption of robots in the manufacturing sector had a positive effect on employment in nonrobot services.[14] And except for the direct effect, most of the employment created (or lost in the case of domestic supplier linkages) in value chains is due to robotization in the manufacturing sector (see Figure 2.22), even though a large share of jobs were created in non-manufacturing sectors (see Figure 2.21).

The highest contributions to employment from robotization came in computers and machinery and in basic metals

Among industries, only chemicals and pharmaceuticals had a negative impact on the economy-wide employment that resulted from the greater use of

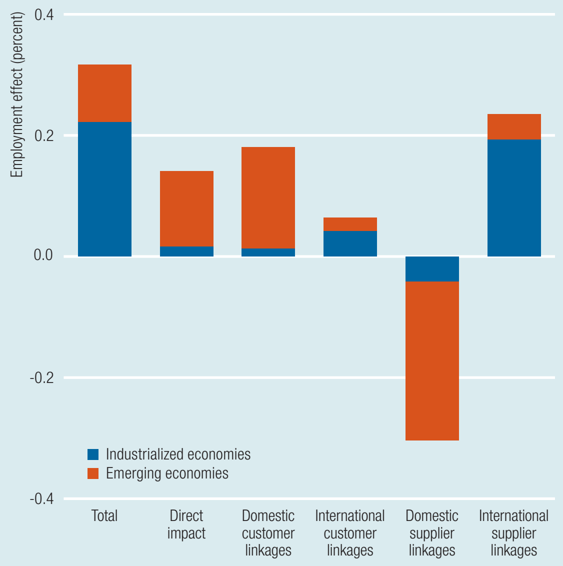
“Manufacturing accounts for two-thirds of the growth in world employment attributable to the adoption of robots

Figure 2.19
Where were jobs created? Employment growth due to robots, by economy groups, 2000–2014



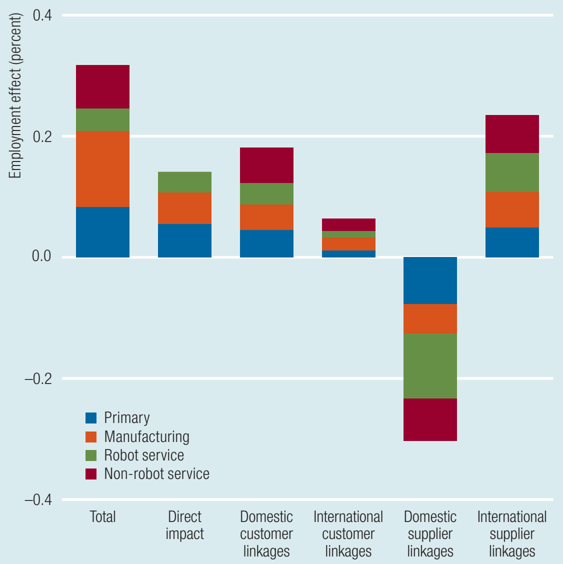
Note: Coefficients are applied to the weighted averages of the growth rates of the stock of robots across economies and industries. Coefficients are from estimations in Ghodsi et al. (2019), Table 6 (model 1).
Source: UNIDO elaboration based on dataset by Ghodsi et al. (2019) based on Timmer et al. (2015).

Figure 2.20
Who created the jobs? Employment growth due to robots, by economy groups, 2000–2014



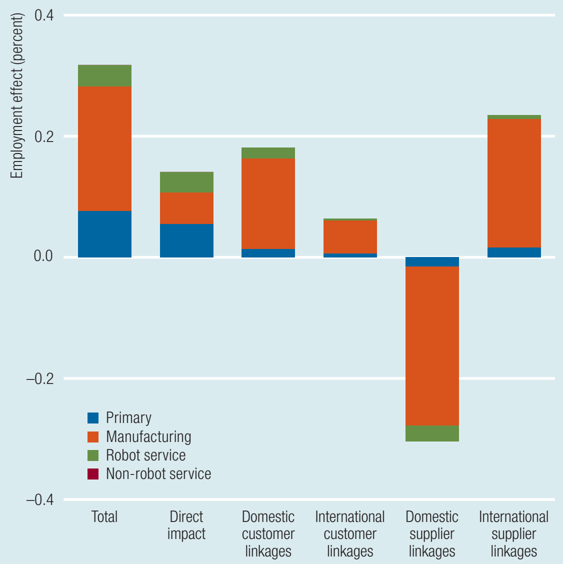
Note: Coefficients are applied to the weighted averages of the growth rates of the stock of robots across economies and industries. Coefficients are from estimations in Ghodsi et al. (2019), Table 6 (model 1).
Source: UNIDO elaboration based on dataset by Ghodsi et al. (2019) based on Timmer et al. (2015).

Figure 2.21
Where were the jobs created? Employment growth due to robots, by sector, 2000–2014



Note: Coefficients are applied to the weighted averages of the growth rates of the stock of robots across economies and industries. Coefficients are from estimations in Ghodsi et al. (2019), Table 6 (model 1).
Source: UNIDO elaboration based on dataset by Ghodsi et al. (2019) based on Timmer et al. (2015).

Figure 2.22
Who created the jobs? Employment growth due to robots, by sector, 2000–2014



Note: Coefficients are applied to the weighted averages of the growth rates of the stock of robots across economies and industries. Coefficients are from estimations in Ghodsi et al. (2019), Table 6 (model 1).
Source: UNIDO elaboration based on dataset by Ghodsi et al. (2019) based on Timmer et al. (2015).

> **It is unrealistic to evaluate the impact of robotization on employment based exclusively on technological replacement potential**

robots. The positive contributions to employment creation were heavily concentrated in a few industries. In only three industries was the employment contribution larger than the average for manufacturing, and the contributions were much higher in the top two industries than in the top third (Figure 2.23). The highest contribution was in the computer and machinery industry, through higher employment in international suppliers in the same value chain. The second highest contribution was in the basic metals industry. Thus, one of the two TDI industries—computers and machinery—is also prominent in job creation through the adoption of robots.

Future effects of robotization may be different

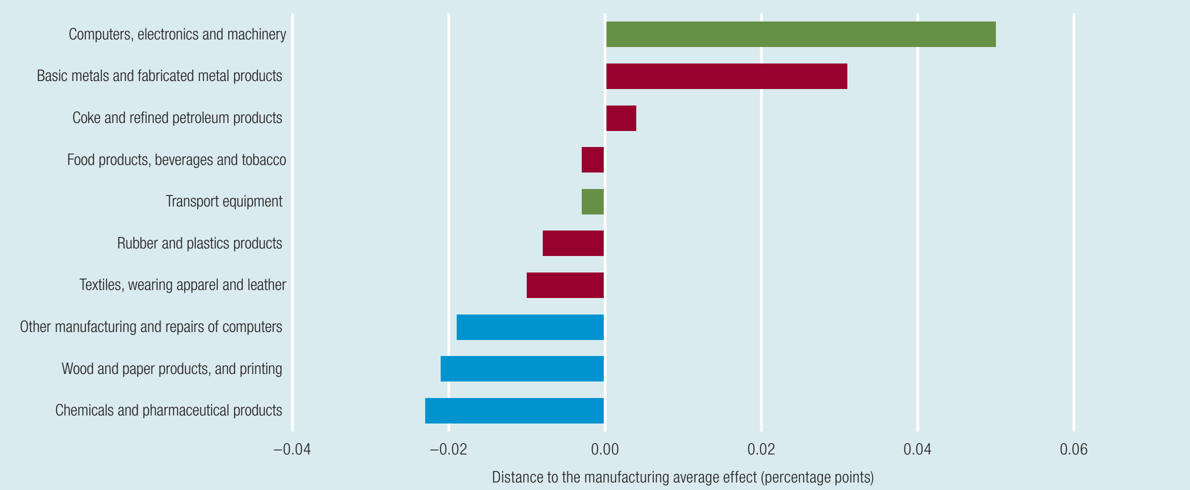
Due to the fairly recent takeoff of robotization and the small number of emerging industrial economies in this analysis, it would be difficult to project future trends based on these empirical results. For example, if the growth in the use of robots to date has been associated mainly with the production of new products but will be increasingly associated with production process efficiency in the future, the impact of robotization on employment could be less favourable than in the current analysis. But it is also unrealistic to evaluate the impact of robotization on employment based exclusively on technological replacement potential, as earlier studies have done (Frey and Osborne 2017).

A more detailed picture of employment and output effects

In a study of Germany, robotization did not increase workers' risk of displacement

Recent studies using long-term firm-level and worker-level data reveal a more fine-grained picture of the labour market response to robotization and provide a more nuanced and holistic assessment of the impact of robotization. For example, Dauth et al. (2018), based on worker-level evidence in Germany for 1994–2014, show that the adoption of robots has not increased the risk of displacement for incumbent manufacturing workers. Workers seem to have adjusted to the installation of robots by switching jobs within the same firm. As does the analysis in this chapter, Dauth et al. also provide evidence on the complementarity and expansion of economic activity in other industries as an important adjustment mechanism.

Figure 2.23
Computer, electrics and machinery and basic metals are the main creators of jobs due to automation



Note: Coefficients are applied to the weighted averages of the growth rates of the stock of robots across economies and industries. Coefficients are from estimations in Ghodsi et al. (2019), Table 8. 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 both. Red = industries that are intensive on neither digitalization nor technology.
Source: UNIDO elaboration based on dataset by Ghodsi et al. (2019) based on Timmer et al. (2015).

> **Output growth due to robot adoption needs to be considered in addition to the effect on production processes**

In a study of Spain, robotization reduced labour cost share but increased the number of jobs

Koch et al. (2019) examined the impact of robot adoption on individual firms using a panel dataset of manufacturing firms in Spain over 1990–2016. They found that robotization led to substantial gains in output while reducing the labour cost share. But because the output gains were much larger than the reduction in the labour cost share, firms that adopted robots generated jobs while firms that did not adopt robots had substantial job losses. The same could be said for other ADP technologies. For example, in the South African machinery and equipment industry, firms that initially cut jobs following the adoption of automation and artificial intelligence reabsorbed employees in different divisions as their output increased as a result of the adoption of the new technologies (Kaziboni et al. 2019).

So, output growth is another possible effect of robotization

Thus the possibility of output growth due to robot adoption needs to be considered in addition to the effect on production processes (increasing capital intensity) relative to nonadoption. If greater use of robots makes production management easier and increases capital's income share relative to labour's without boosting firm or industry competitiveness or output by much, robot adoption is likely to have a negative impact on employment. But if robot adopters experience much faster growth than nonadopters—due to increased production scales and intersectoral complementarity, redistribution of work in a value chain and relocation of workers within a firm—firms and industries adopting robots are more likely to generate jobs than are nonadopters.

Notes

1. This report looks at the following 10 industries, which are combinations of subsectors at the ISIC(rev.4)-2 digit level: food products, beverages and tobacco (ISIC 10t12); textiles, wearing apparel, leather (ISIC 13t15); wood and paper products, and printing (ISIC 16t18); coke and refined petroleum products (ISIC 19); chemicals, chemical products and pharmaceutical products (ISIC 20t21); rubber and plastics products (ISIC 22t23); basic metals and fabricated metal products (ISIC 24t25); computers, electronics and machinery (ISIC 26t28); motor vehicles and other transport equipment (ISIC 29t30); and furniture, other manufacturing and repairs of computers (ISIC 31t33).
2. The classification of manufacturing industries by technology intensity is based on research and development (R&D) intensity as documented in OECD (2011), while the classification by digital intensity is based on seven dimensions of digital transformation including ICT investment, software investment, ICT intermediate goods, ICT intermediate services, robot use, online sales, and ICT specialists, as discussed in Calvino et al. (2018).
3. Broadly defined as sectors C71RMQ (Renting of machinery and equipment), C72ITS (Computer and related activities), and C73T74OBZ (R&D and other business activities) from the OECD's Inter-Country Input-Output Tables (ICIO).
4. This has been the focus of a wide body of literature such as in Ciriaci and Palma (2016), Consoli and Elche-Hortelano (2010), den Hortog (2001), Muller and Zenker (2001), Shearmur and Doloreux (2013), and Strambach (2018).
5. This section is based on the UNIDO background paper prepared by Sorgner (2019).
6. The Skills Towards Employability and Productivity (STEP) program (https://microdata.worldbank.org/index.php/catalog/step), designed by the World Bank, implements standardized surveys to gather internationally comparable data on the supply and distribution of skills and the demand for skills of adult population in the labour market of developing countries. So far, STEP was administered in two waves, 2012 and 2013, in 13 countries: Armenia, Colombia, Georgia, Ghana, Kenya, Lao People's Democratic Republic, North Macedonia, the Philippines, Sri Lanka, the

Plurinational State of Bolivia, Ukraine, Viet Nam, and China's Yunnan province. For data comparability reasons, Philippines and China's Yunnan province were excluded from the sample for the analysis here. For more information on the sample, see Sorgner (2019).

7. The approach measures the risk that an occupation will be completely computerized in the near future. This is done projecting the estimates from Frey and Osborne (2017) into the individual worker characteristics and a broad subset of task characteristics reported in the STEP dataset. See Sorgner (2019) for the details.
8. These results are in line with the analysis by Grundke et al. (2017) based on the OECD's Survey of Adult Skills (Programme for the International Assessment of Adult Competencies, PIAAC) data, showing that women lag behind men in quantitative and mathematics-related skills, while gender differences are small in soft skills, such as self-organization, management and communication.
9. These results are (qualitatively) in line with similar studies using PIAAC data to analyse the susceptibility of the female workforce to automation in OECD countries. Brussevich et al. (2018) find that 9–10 percent of the male and female workforce face higher than 70 percent computerization risk, slightly larger the proportion of the female workforce at risk.
10. Broadly speaking, there are two types of robots (see Glossary): industrial robots, which are used in manufacturing processes, and service robots, which are used in other sectors of the economy. This section looks exclusively at industrial robots.
11. Unlike most of the literature, this section looks at both industrialized and emerging industrial economies and includes the effects of international input-output linkages. The analysis of the implications of robots for labour markets is integrated into the framework developed by Autor and Salomons (2018). For the econometric model used in the analysis of this section, refer to Ghodsi et al. (2019). The analysis 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).
12. The analysis in this section focuses on the 43 economies included in the World Input-Output Database (WIOD, Timmer et al. 2015). See Annex C.1, at the end of the report, for the full list of economies included.
13. It cannot be ruled out that the result is biased upward because emerging industrial economies included in the WIOD show large growth of robots due to the small number of robots in the first years and thus get relatively large weights.
14. The nonrobot service sector includes all service activities except education, construction, veterinary activities, electricity and water supply, scientific research and development, and other professional, scientific and technical activities.

Chapter 3

How manufacturing firms can absorb and exploit advanced digital production technologies

This chapter offers a firm-level view of the debate about the emerging advanced digital production (ADP) technologies. This view is crucial, since ADP technologies are adopted not by countries or sectors, but by firms. The diffusion of ADP technologies and their effective use largely depends on firms' ability to acquire and develop the necessary capabilities, particularly where they are still scarce, as is often the case in developing and emerging economies.

Qualitative firm-level evidence on the adoption of ADP technologies and its implications

This chapter presents a set of firm-level case studies on adopting, absorbing and effectively using ADP technologies in developing and emerging economies. The cases indicate positive impacts for competitiveness, the quantity and quality of products, ground-breaking business models and environmental sustainability. To produce these impacts, firms must often overcome such challenges as the lack of qualified personnel and the evolution of roles within the firms. The extent of these technological breakthroughs actually permeating the industrial structures typical of an emerging or developing country are not yet clear. They may, instead, increase polarization and exacerbate existing productive heterogeneity. Weak connections between technologically advanced firms and local actors can prevent a broader impact from the new technologies.

Firm-level evidence in Argentina, Brazil, Ghana, Thailand and Viet Nam

This chapter also presents and discusses new quantitative evidence on ADP technologies collected by UNIDO through original firm-level surveys in five countries—Argentina, Brazil, Ghana, Thailand and Viet Nam. The data show that a small percentage of firms adopt the most advanced production technologies and that their diffusion is still far from a mass phenomenon. When other firms' expected technological trajectory is considered, only a minority are engaging or getting ready to engage with ADP technologies and can thus be categorized as forging ahead or catching up. Strong technological and production capabilities and participation in global value chains (GVCs) facilitate the uptake of new technologies.

Impacts on revenue and productivity—and more

When ADP technologies are in place, revenues and productivity are expected to increase. But the current policy debate warns of possible negative impacts on employment. In the UNIDO firm-level data, however, the majority of technologically advanced firms foresee the impact on employment to be neutral or positive. The fear of job displacement from new technologies is thus counterbalanced by the creation of new jobs related to new skills and the use of new machines. This is in line with the positive effects on employment expected from the diffusion of robots discussed in Chapter 2.

ADP technologies increase demand for technology-related and science, technology, engineering and mathematics (STEM) skills and maintain demand for soft skills. These features may increase the risk of displacement of female workers, who tend to have gaps in these skills compared with male workers (Chapter 2). Yet, the surveys collected for the Industrial Development Report (IDR) 2020 suggest that firm-level adoption of ADP technologies create more employment opportunities for women with STEM skills.

The diffusion of ADP technologies may also trigger the adoption of more sustainable practices for materials, waste and energy. Improved productivity could lower prices and increase demand, needing to be counterbalanced by more efficient use of inputs in production.

Backshoring is not widespread

Is backshoring—shifting production to industrialized countries from developing ones—a major

> **Evidence is still scarce about the implications for manufacturing firms of ADP technologies**

threat? This report finds that it is quite rare and is still counterbalanced by firms' offshore production in developing countries, creating further opportunities for jobs and backward and forward value chain linkages.

Getting the most out of it by building on production capabilities

This chapter shows that firms' introduction of technological innovation, such as process innovations, is strongly related to industrialization or production capabilities derived from experience and learning by doing. These provide the main point of entry for adopting new technologies in emerging country firms and appear to be more important than technological and investment capabilities. Together, investment and technological and production capabilities deliver a higher adoption rate of new technologies than any of them taken separately.

Digitalization as necessary condition

Digitalization is another essential precondition for engaging with ADP technologies. If basic infrastructure such as electricity, internet connection and use of email is not in place, firms cannot adopt, absorb or use digital technologies. This chapter points out that only a small percentage of enterprises are digital leaders that can combine solid technological capabilities—including research and development (R&D) expenditure and the ability to introduce new products—with automation, new processes and all forms of digital communication. A larger group of firms in emerging and developing countries can perform some of these activities and could fruitfully take steps towards more advanced digital technologies. These firms appear to have a higher propensity to export and to generate employment.

Production capabilities are key for industrial and innovation policies

Overall this chapter emphasizes that new opportunities from engaging with ADP technologies may come from an increasing role for soft skills, whose importance within the set of "skills of future" is found to be growing, and from the combination of production capabilities, which normally belong to the industrial policy sphere, with technology and investment capabilities, which traditionally occupy the technology policy debate. Recognizing the importance of production technologies widens the perimeter of the policy space facilitating technology adoption, but at the cost of greater complexity due to the higher sophistication of the new technologies.

ADP technologies: What's in it for firms in developing countries?

Big hype, little evidence

ADP technologies are at the centre of global debates

ADP technologies increasingly attract attention as a source of revenues and a field of competitiveness for firms. Thanks to their expected firm-level impacts (see Figure 1.10 in Chapter 1), new technologies have become a major topic of policy debates in advanced economies, both because they can boost firms' long-term productivity and because economic sluggishness makes it urgent to find new sources of growth (OECD 2017). They have also started to occupy the centre of the policy debate in developing and emerging countries as the new frontier of competitiveness. Although the academic and policy debate on the latest digital production technologies has been growing impressively, its insights are mostly anecdotal and often inconclusive, not yet justified by systematic and sound assessments based on solid data. Evidence is still scarce about the micro-level implications for manufacturing firms of ADP technologies, especially in developing and emerging countries.

Most firm-level data come from international consulting firms

Most currently available firm-level information on the diffusion and impact of ADP technologies comes

> **Lack of capabilities is a major obstacle to technological upgrading**

from executive surveys carried out by international consulting firms (Abood et al. 2017; Deloitte, 2018; McKinsey Global Institute 2017; PwC 2016, 2018). These analyses help by assessing the diffusion of specific technical solutions and their perceived benefits, and they often propose ways to evaluate enterprise readiness to incorporate such technologies. But they have limited representativeness and tend to focus exclusively on large enterprises in advanced economies. Other sources of firm-level evidence on new production technologies are scarce, mostly due to the lack of micro-level data collection. Recently some specific surveys have been implemented (such as the European Manufacturing Survey—EMS—and the Community survey on ICT usage and e-commerce in enterprises by Eurostat); yet, these consider only European countries, and information about developing country firms and advanced production technologies remains very limited.

Diffusion of ADP technologies is still limited, according to the scarce evidence available

Even in the available firm-level data from advanced economies, the diffusion of ADP technologies appears to be still too limited for sound assessments. Despite sensationalistic announcements of an ongoing disruptive revolution, only a few companies are actually engaging with new digital production technologies. Studies on technologies associated with the fourth industrial revolution (4IR) among small and medium-sized enterprises (SMEs) in Germany and the Republic of Korea suggest that only around 18–20 percent of companies have engaged with them and are familiar with the concept (Sommer 2015). In Europe, only 6 percent of information and communications technology (ICT) and professional services companies are making strategic and intense use of data, and fewer than 1 percent of employed personnel are data specialists (EPSC 2017). It is thus not surprising that firm-level evidence on the impact on productivity and employment of ADP technologies is still scarce and inconclusive, particularly in developing and emerging economies.

Getting ready for ADP technologies

How can developing country firms engage with advanced technologies?

The discussion about developing countries and ADP technologies has mostly focused on issues related to the adoption of new technologies by actors in advanced economies, such as backshoring or changes in the structure of GVCs. Less discussion has covered how developing country manufacturing firms can adopt and effectively exploit ADP technologies.[1]

Firm capabilities are preconditions of adopting and effectively using new technologies

Lack of capabilities is a major obstacle to technological upgrading for firms in developing countries. In the latest technological wave, the diffusion of ADP technologies requires firms to acquire the necessary capabilities—executable routines or procedures for repeated performance in a specific context, produced by learning in an organization (Cohen et al. 1996). Since new production technologies build on and coexist with more mature ones, firms need to develop a broad array of conventional and new capabilities to adopt the new technologies and embed them effectively in existing production organizations (Bogliacino and Codagnone 2019).

Firm capabilities are diverse

Three broad sets of capabilities stand out: investment, technological and production capabilities. Investment and technological capabilities enable a firm to deal with technological change. They include the resources, skills and technological knowledge needed by firms 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 production experience, learning by doing and behavioural and entrepreneurial factors. Given the complex, interconnected and flexible nature of ADP technologies, production capabilities are becoming increasingly important. They represent the first step

Acquisition and development of capabilities are often complex and gradual

to acquire the base needed for further technology improvements.

Firm capabilities are accumulated gradually

But the acquisition and development of capabilities is not easy or linear. Acquiring them is often complex and gradual. Distinguishing firm capabilities into basic, intermediate and advanced conveys the incremental steps whereby companies accumulate capabilities over time (Table 3.1).

Capabilities as a roadmap for cumulative learning

Firms and countries first industrialize and acquire basic capabilities, then upgrade towards higher levels of technology. Mastering the basic capabilities—mostly associated with production—is critical for effectively deploying new technologies and retaining efficiency as well as for further developing firm capabilities. This means that a company would find it extremely difficult to develop capabilities in advanced robotics if it were still struggling to arrange its production flow and

Table 3.1

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

> **Developing basic and intermediate capabilities depends on an industrial ecosystem in which firms operate**

Table 3.1 (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).

supply logistics so it could feed robots with intermediate components in an organized environment and without disruption. Thus, firms need to surpass a minimum threshold of basic and intermediate capabilities before inserting new technologies in their production organization. Developing basic and intermediate capabilities depends on an industrial ecosystem in which manufacturing firms can operate and learn.

Basic and intermediate capabilities are a pre-condition for developing more advanced capabilities, such as production system integration capabilities. Advanced capabilities allow rethinking the organization and structure of production processes to optimize the potential of ADP technologies.

Systemic capabilities are also necessary. These relate to the broader ecosystem in which firms operate and to other framework and systemic conditions, including infrastructure.[2] As mentioned in Chapter 1, adopting and exploiting the potential of ADP technologies presupposes the presence of digital

> **Inadequate digital infrastructure can inhibit the adoption of digital industrialization**

infrastructure. Inadequate digital infrastructure can inhibit the adoption of digital industrialization and thus offset any potential gains from it. For example, the lack of high-speed data access was one of the main obstacles to the diffusion of predictive maintenance technologies in the machinery and equipment sector in South Africa (see Box 2.1 in Chapter 2).

Each company is a unique bundle of capabilities

Each company is a unique bundle of capabilities (Andreoni and Anzolin 2019). As different companies face different learning challenges, their pace of developing new capabilities is likely to be uneven. In developing countries, this reinforces firm heterogeneity, leading to a large number of low-capability and low-performance actors coexisting with more advanced ones. In developing countries, not only do firms face the divide separating them from firms in advanced economies operating close to the digital frontier, but a wide country-level divide—the digital capability gap—is present between the most digitally and technologically advanced companies and the rest.

The digital capability gap may harm advanced as well as low-capability firms

The gap's direct consequence is the generation of 4IR islands—that is, a few major leading companies engaging with some ADP technologies operating as islands in a sea of firms with scarce capabilities that still use older production technologies. Advanced companies may be harmed by this gap, because they may have trouble linking backwards to local actors and thus nurturing their supply chains. So, the digital capability gap impedes the diffusion of ADP technologies, turning a technology upgrading opportunity into a digital industrialization bottleneck. Smaller companies may find their own way to compete outside the technology leverage, but they may also play a role in the adoption of ADP technologies. A key challenge for developing economies 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).

Field case studies: A qualitative approach

This section documents the experience of some technologically advanced firms in developing countries. The cases were collected in 2019 across eight developing and emerging industrial economies.[3] For each firm, the analysis explores different impact dimensions related to the framework presented in Chapter 1 (Table 3.2). The analysis also investigates the micro mechanisms of technology upgrading, describing why and how firms adopt and absorb advanced production technologies and what factors facilitate or challenge the diffusion of these technologies.

Exploiting the potential of ADP technologies

Enhanced efficiency and flexibility boost competitiveness

The firms interviewed reported improved efficiency, output and sales revenues as a result of reduced operational costs, optimized use of inputs and lower inventories. Thanks to a new production line updated by Siemens's intelligent software, China Baowu Steel Group Corporation (commonly known as Baowu) increased its average daily output by 15–30 percent and reduced excess inventory in the warehouse by half, improving labour efficiency by 10 percent while reducing costs by 20 percent. Also in China, the new Haier air conditioning smart factory, which required investing in equipment interconnections and digital systems approximately 1.2 times those of a conventional factory, had a 60 percent improvement of operational efficiency.

Improved competitiveness is more than an enhanced efficiency story: It's also about quality…

New technologies improved precision and reduced errors at almost all interviewed firms. They allowed firms to operate with higher quality in processes and products, and to eventually expand into new or higher-end markets. Baowu expects the adoption of Alibaba Cloud ET Industrial Brain, powered by artificial intelligence, edge computing and augmented reality, to reduce the factory's nonconforming product rate by

New technologies improved precision and reduced errors at almost all interviewed firms

Table 3.2
Case studies examined the impact of advanced technology on the competitiveness, environmental sustainability and social inclusiveness of developing country firms

			AEDesign Pakistan Engineering services	Arçelik Turkey Washing machines	AVS Technology AG Uruguay Chlorine plants	China Baowu Steel Group Corporation China Steel	Genesis Bionics Kyrgyzstan Bionic prostheses	Haier China Air conditioning systems	Mahindra & Mahindra India Automotive	New-Tek Kyrgyzstan Solar panels	Penang Automation Cluster Malaysia Metal components	Thales 3D Morocco Components for aerospace sector	ZC Rubber China Rubber and tires
New and better products	New solutions for marginalized groups	• Medical devices at affordable prices					●						
	Better quality and new business models	• Personalized products, mass customization • New and data-based services • New pricing models		●	●		●	●		●		●	
	Environmental goods	• Goods produced with eco-friendly materials • Increased product energy efficiency					●	●		●			
Increased production efficiency	Energy efficiency and input optimization	• Emission and waste reduction • Acceleration of circular economy transition	●	●	●	●		●		●		●	●
	Operational cost reduction	• Flexible and decentralized production • Supply chain connectivity, delivery performance and logistics • Agile, adaptive organization		●		●		●					
	Improved capital utilization	• Productive and automatic maintenance, downtime reduction • Lower inventory rate, increased cash-to-cash cycle			●	●				●			
	Employment quality and linkages to services	• Improved work conditions, safety • Foster female employment • New skills, task efficiency	●	●		●		●	●	●	●	●	
Affecting adoption	Enablers	• External knowledge • Pre-existing industrial and production capabilities	●	●	●	●	●	●		●			●
	Challenges	• Lack of qualified personnel • Changing internal culture						●		●	●	●	●

Note: The circles identify the topics covered in each case study.
Source: UNIDO elaboration based on Calza and Fokeer (2019).

> **New production technologies can generate positive environmental spillovers by reducing hazardous and polluting processes**

28 percent. At the Kyrgyz New-Tek plant, which produces solar panels employing an innovative fully automated production line, industrial robots controlled by sensors via a general production control program minimize inaccuracies and errors. This high-precision production is reflected in the superior quality and competitive price of solar panels, which obtained the quality certifications required to sell to the markets of the European Union and the United States.

...and sustainability

Environmental sustainability is associated with ADP technologies for three main reasons: improved energy efficiency, sustainable materials, and reduced waste and pollution. First, companies experience energy efficiency gains, especially in heavy industries. Baowu increased its energy efficiency by 5 percent, while ZC Rubber's energy efficiency improved by more than 10 percent. Second, additive manufacturing achieves more efficient and sustainable use of materials than subtractive production processes by consuming less energy and minimizing waste (OECD 2017). So far, 3D printers often employ metals or plastic, but efforts are increasing to develop new environmentally friendly materials, such as the PLA-plastic based on sugarcane and corn used by the Kyrgyzstan-based Genesis Bionics for 3D-printed bionic prostheses. Finally, new production technologies can generate positive environmental spillovers by reducing hazardous and polluting processes. The smart modular plants for producing chlor-alkali directly at water treatment plants developed by Uruguayan AVS Technology AG eliminate the need to store or transport chlorine in liquefied gas form, whose leakages could harm both human health and the environment.

New products and new business and organizational models emerge from ADP technology

New production technologies go beyond improving processes. They also entail new products and new business and organizational models. Some changes are already visible, mostly in new business models and "servification"—that is, manufacturers offering services, often attached to products. Technologies "have never transformed industries on their own" but they need business models promoting transformation through agile organization, a collaborative ecosystem and more customization (Kavadiaset al. 2016).

ADP technologies shape factories and manufacturing processes as well as products

The experiences of the smart washing machine produced by Arçelick and the smart air conditioning system produced by Haier are prototypical. Products are made in smart factories through industrial platforms that connect the entire supply chain in real time, from suppliers to final users, who customize the product according to their needs and tastes. This enhanced supplier–producer–user interaction has two implications. It changes the business model from "manufacturer designing" to "customers designing," allowing user-led innovation into production. And it changes the nature of the product from analogue to digital and smart: smart products transmit data back to manufacturers, who analyse them to improve processes and to develop after-sales services attached to the physical product and increasing its value.

3D printing makes complex products without costly tooling

Additive manufacturing provides another example of how ADP technologies can bring new products into the market. 3D printing, together with computer-aided design (CAD) programs, allows the realization of products that conventional manufacturing could not produce because of their complex internal structure or the need to first produce a complicated and expensive mould. 3D printing technology enables the production of complex parts without costly tooling, eliminates the design-for-manufacturability constraints of conventional subtractive manufacturing processes and allows customized products, ranging from the prosthetic hands made by Genesis Bionics to the metal components made by Thales 3D.

ADP technologies reshape skills, work conditions and roles

New technologies lead to a profound redefinition of workers' skills and roles throughout production. As

> **Pre-existing industrial and production capabilities are crucial to absorbing and using ADP technologies**

digitalization permeates all stages and tools, workers need a deep knowledge of digital technologies and digital skills to understand and integrate new technologies into their tasks. On top of the hard skills needed for automation, coding, data analytics and data-driven decision-making, workers increasingly need soft skills, such as the ability to learn and communicate.

In addition, some firms are changing roles more radically: production workers increasingly operate as platform managers, coordinating customers' requests and interacting with suppliers, instead of performing traditional mechanical repetitive tasks. The new roles also require negotiation and coordinating skills. This evolution has been described especially by firms implementing fully smart factories for customized smart goods, operating with digital industrial platforms, such as Haier, Arçelik and Mahindra & Mahindra Ltd. (M&M).

Automation removes workers from backbreaking and hazardous tasks

Digital operating systems and automation technologies are also expected to move workers away from the most physically demanding and hazardous tasks. Some firms interviewed—such as Baowu, M&M and New-Tek—highlighted this. They also identified this removal of physical job requirements as potentially helpful to expanding female employment in traditionally male-dominated manufacturing tasks.

Adopting and absorbing ADP technologies

The main challenge is humans, not robots

For most firms interviewed, the lack of qualified personnel is the main challenge to adopting and using ADP technologies, greatly limiting the speed of transformation. Since higher education institutions are scarce and often do not offer adequate programs, New-Tek and Thales 3D arranged training abroad with foreign partners and developed internal training programmes. The lack of talent is particularly serious among women, since fewer of them pursue careers in digital technologies, engineering and mechanics.

Absorbing new roles and routines is difficult

Changing a firm's culture is another major challenge. Both Haier and ZC Rubber emphasized how difficult overcoming the inertia of consolidated routines and deeply rooted thinking modes is, as well as adjusting the organization to new roles and requirements. So, even if adopting new equipment may not present a big challenge—even financially—absorbing complex and rapidly evolving technologies into production processes remains a difficult task, even for firms already familiar with digital technologies.

The adoption of advanced digital production technologies is not binary—it has shades

The adoption of new technologies is usually modelled as if firms face a yes-or-no choice. Yet adoption seems to have shades: firms do not fully adopt or fully reject a technology—they tend to incorporate one gradually, starting with only some functions. The case studies showed that, even if automated and interconnected production lines were installed, other business functions remained at a less advanced technological level. For example, purchase orders were forwarded by email, product design relied on unconnected 3D modelling programs, or customer relations were updated manually in spreadsheets.

Previous industrial and production experience helps in setting up smart factories

The case studies shows that pre-existing industrial and production capabilities are crucial to how manufacturing firms in a developing country adopt, absorb and use ADP technologies. The production experience of Baowu and ZC Rubber was fundamental in providing accurate and rich information for fine-tuning and adjusting system parameters during technology upgrading. The organizational competences developed in decades of white goods production by Arçelik and Haier were crucial for setting up new smart factories. These results confirm the importance

> **Firms tend to access new technologies mostly through an external source**

of the industrial base and industrial capabilities discussed in Chapter 1.

Adopting new technologies is a stepping stone to technological learning

Firms tend to access new technologies mostly through an external source—a university (Genesis Bionics), a foreign partner making a direct investment (New-Tek), a foreign digital leader (Baowu through Siemens) or a domestic one (ZC Rubber through Alibaba ET Industrial Brain)—in a cooperation agreement, often supported by the government. Even if technologies are mostly imported or developed outside the firm, adopting them represents a valuable opportunity for technological learning. Indeed, all cases include some degree of endogenous innovation. So, firms do not just replicate new technologies, they also adapt them to specific processes and conditions, eventually leading to newpatents and new machinery, as shown by the new steel melting crane developed by Baowu and Siemens; new software and programs, such as the COSMOPlat platform developed by Haier; and the electromyography method developed by Genesis Bionics. Such "follow-on or incremental innovations" (Lee and Ki 2017) support the argument in Chapter 1 that adopting external technology with a local twist is a stepping stone for learning and mastering advanced technologies, and for developing domestic technological capabilities (Lee 2019).

Only a few isolated firms use ADP technologies

The few companies adopting ADP technologies may find it difficult to generate linkages with surrounding firms due to the large digital capability gap that separates them form the rest of the manufacturing sector (Andreoni 2019). The case studies seem to confirm the existence of 4IR islands, since the interviewed firms represent exceptions, not average manufacturing firms, in using advanced production technologies. Most said they rely on qualified foreign suppliers that can match their technological level and their speed and quality requirements.

Yet, technologically advanced firms can develop ties with local actors

Yet, these technologically advanced firms still generate ties with local market and nonmarket actors. Some actively engage with local industry associations and universities, leading to joint training, student internships and joint scientific and technical research, as in the case of Thales 3D in Morocco. For New-Tek in Kyrgyzstan, local ties went as far as sharing facilities and laboratories for testing. Some firms even developed linkages with the local industrial ecosystem, which provides inputs and postproduction support. This suggests that even the most technologically advanced firms may need the support of actors using older technologies. For example, Thales 3D relies on actors using conventional technologies to finalize its high-quality products (Calza and Fokeer 2019). And in the Penang Automation Cluster in Malaysia, large technological companies use local firms still employing previous-generation production technologies for some simpler tasks. Thus, even 4IR islands may engage in some local linkages; yet, it remains unclear to what extent this can contribute to effective technology transfer to local firms.

Firms vary in hiring trends, government support, foreign ownership and location decisions

Some other relevant issues seem to be firm-specific, with few common traits. The magnitude and direction of the changes in employment is not homogenous: the case studies display scenarios ranging from the replacement of heavy jobs by automated machinery to the increase in workers with digital skills. The role of government also differs: in some cases, it has explicitly supported the transfer and adoption of new technologies, while in other cases, it has offered no support. Finally, some of the firms interviewed are partially or totally foreign-owned, and their reasons to operate in a developing country are heterogeneous: location in a Free Economic Zone (such as New-Tek in Kyrgyzstan and AVS Technology AG in Uruguay) or an industrial park (such as Baowu and Haier in the Sino-German Ecopark of Qingdao), and nearness to final customers

> Various generations of production technologies tend to be used at the same time

(Arçelik in Turkey and Thales 3D in Morocco) seem to be the most frequent. None of these firms referred to lower labour costs as a major factor, emphasizing instead the industrial ecosystems, qualified talent or geographical proximity to target markets.

A micro-level perspective based on surveys

More data are needed on ADP technologies in developing and emerging economies

Empirical evidence on the diffusion and impact of ADP technologies among firms in developing and emerging countries is scarce. How diffused are the technologies in those economies? What are the implications for firms employing the technologies? How to characterize digital companies as "advanced" or "lagging behind"? As these questions become more urgent, direct surveys and other empirical work on firms are becoming necessary.

Surveys provide new evidence on technology adoption and its effects

This chapter contributes evidence based on firm-level surveys between 2017 and 2019 in Argentina, Brazil, Ghana, Thailand and Viet Nam. The surveys had a twofold aim: they investigated the patterns of adoption of digital production technologies in developing and emerging economies, and they explored the technologies' firm-level implications for productivity, employment and skills, location of production and environmental sustainability.

UNIDO surveys

Various generations of production technologies are used at the same time

Heterogeneity is characteristic of the productive structure in developing and emerging economies.[4] In the countries covered by the surveys, many levels of capabilities and competences are likely to coexist in the productive structure of each country, between and within sectors and even within firms. This means that manufacturers employ different production technologies. On one side there are companies producing goods and services through more traditional processes without using digital technologies. At the other extreme there are companies that include digitalization as an essential part of business strategy.

The concept of firm heterogeneity lies at the core of the UNIDO surveys. It inspired the structure of the surveys, whose original feature is to investigate a range of possible technological levels or generations within each country's productive structure. The approach differs from existing micro-level surveys—such as EMS, Eurostat and executive surveys carried out by international consulting firms. They tend to cover individual ADP technologies while disregarding digital solutions that have been around for a long time yet but may still be relevant to firm-level performance.

The surveys conducted for this report acknowledge that various generations of production technologies tend to be used at the same time, particularly in emerging or developing economies. The surveys pursued a broader path in questioning firms about their engagement with digital production technologies. All surveys used a common a framework based on different technological generations that go from simple and analogue ones (generation 0.0) to the most cutting-edge digital production technologies associated with smart production (generation 4.0) (see Figure 1.20 in Chapter 1).[5] This aims to capture the evolutionary logic of incorporating digital technologies in heterogeneous industrial environments.

Diffusing and adopting ADP technologies

Brazil and Argentina have the largest shares of firms using more advanced technologies

Among the five countries considered, Brazil and Argentina have the largest shares of firms using ADP technologies. The other three countries display a lower level of adoption, with differences: Thailand and Viet Nam have a larger share of firms adopting the highest generations of digital technologies (generation 3.0 and 4.0) than Ghana, as well as a larger share of firms using

> **Data confirm heterogeneity across countries as well as within them**

generation 2.0 (Figure 3.1). Ghana has a rather different pattern[6]: not only is the aggregate share of generation 0.0 and 1.0 larger, analogue technologies (generation 0.0) are diffused more widely, with only 11.5 percent of firms using technologies of generation 2.0 and above.

Few firms in any country use the most advanced technologies

Despite large cross-country differences, in every country, the diffusion of higher generations of digital technologies (3.0 and 4.0) is incipient: adopters represent a niche, ranging from 1.5 percent in Ghana to about 30 percent in Brazil. These rates are in line with those in advanced countries, where ADP technologies are not yet diffused on a massive scale, either.

A country's economic structure influences firm behaviour

The differences across countries show how the diffusion of ADP technologies is context-specific. So, the specific features of different countries are important to take into account. Their industries have different geographical locations. The role of their manufacturing firms in GVCs is different. And economic sectors have a different relative importance in their industrial matrix. This diversity supports the coexistence of many patterns of specialization across these different countries.

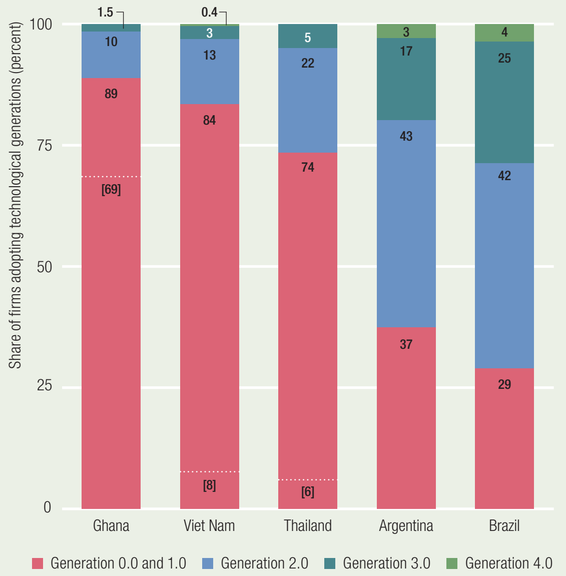
Country technology classifications are supported by firm-level evidence

The results confirm the country-level classification presented in the global characterization in Chapter 1, where Brazil (classified as a follower in production) was the most advanced of the five, followed by Argentina, Thailand and Viet Nam (followers in use) and finally by Ghana (a laggard). The firm-level data provide a consistent and similar picture of cross-country specialization differences.

Different generations of digital technologies coexist within one country

The data confirm heterogeneity across countries as well as within them. Different generations of production technologies coexist within one country. This is not surprising, given the heterogeneity typical of the productive structure of developing and emerging economies. Firm-level data are consistent with the presence of 4IR islands, where a few firms with ADP technologies are surrounded by a majority of firms that operate at a lower technological level.

Figure 3.1
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. Countries are ordered according to the shares of firms currently adopting the highest generations of digital technologies (generations 3.0 and 4.0). See Annex A.3 for more detailed information on sample composition and the methodology of the UNIDO survey, including the definition of technological generations applied in the 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).

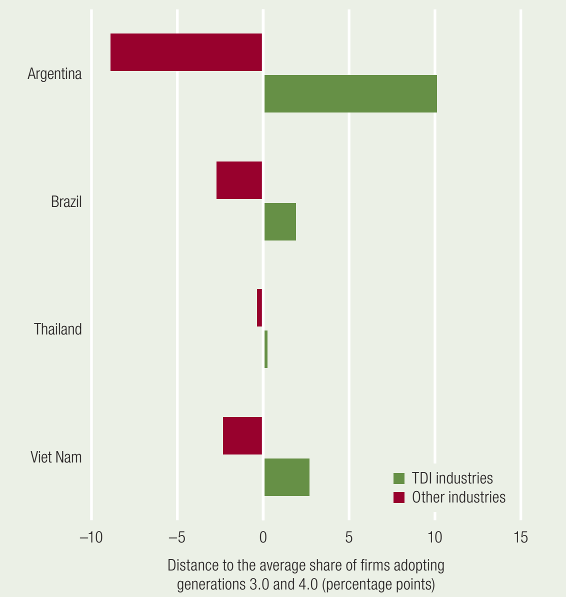
Which characteristics influence the adoption of ADP technologies?

Advanced technologies are more diffused in TDI industries

The share of firms using the highest generations of digital technologies (3.0 and 4.0) is larger in technology- and digital-intensive (TDI) industries (Figure 3.2).[7] This result confirms the sectoral analysis in Chapter 2 (see Figure 2.1) showing how the adoption of new technologies is more widespread in TDI industries.[8]

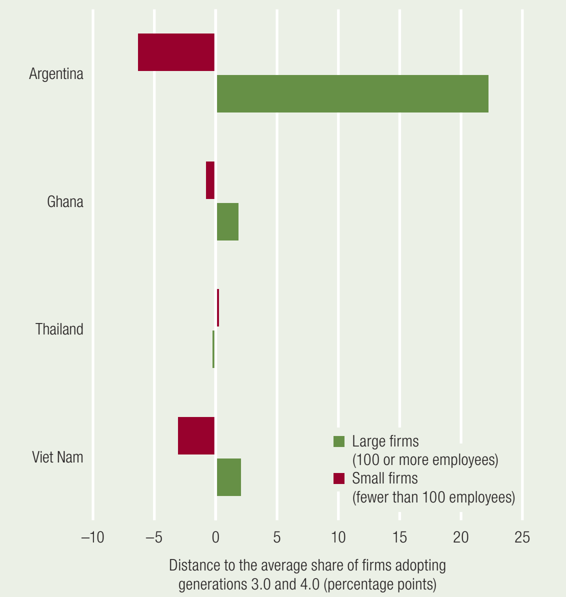
Large firms enjoy technological and productive capabilities that make them more likely to adopt new technologies

Figure 3.2
Firms in TDI industries tend to adopt more ADP technologies



Note: TDI is technology- and digital-intensive. Ghana is excluded from the comparison because the Ghanaian sample does not include TDI industries. TDI industries include automotive and auto parts, and electronics. Other industries include food and beverages; textiles, leather and footwear; plastic and rubber; metal products; and wood and furniture. See Annex A.3 for more detailed information on sample composition and the methodology of the UNIDO survey, including the definition of technological generations applied in the survey questionnaires.
Source: UNIDO elaboration based on data collected by the UNIDO firm-level survey "Adoption of digital production technologies by industrial firms" (for Thailand and Viet Nam) and Albrieu et al. (2019) and Kupfer et al. (2019) (for Argentina and Brazil).

Figure 3.3
Larger firms tend to adopt more ADP technologies



Note: Brazil is excluded from the comparison because the Brazilian sample does not include small firms. See Annex A.3 for more detailed information on sample composition and the methodology of the UNIDO survey, including the definition of technological generations applied in the 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).

However, ADP technologies also exist in other industries. In Thailand, for example, the share of firms using the highest technological generations is similar across different industry groups. Other sectors with lower technology intensity—which tend to be particularly important for low- and lower-middle income countries—could serve as fields for trials of new production technologies.

Larger firms adopt more advanced technologies

Size is another important factor for adopting new technologies. Large firms, thanks to—but not only to—the larger investments their resources permit, tend to enjoy technological and productive capabilities that make them more likely to adopt new technologies. Data on the five countries studied seem to support this argument since a higher share of larger firms adopt the highest generations of digital technologies (3.0 and 4.0) (Figure 3.3).[9] But countries are different: while this pattern is confirmed in Ghana and Viet Nam, and extremely clear in Argentina, the pattern is different in Thailand, where the share of users of generation 3.0 and 4.0 is the same or somewhat lower among large firms.[10] This might suggest that small firms in Thailand do not face systematically higher barriers to adoption than larger firms.

Firm participation in global value chains is associated with advanced technologies

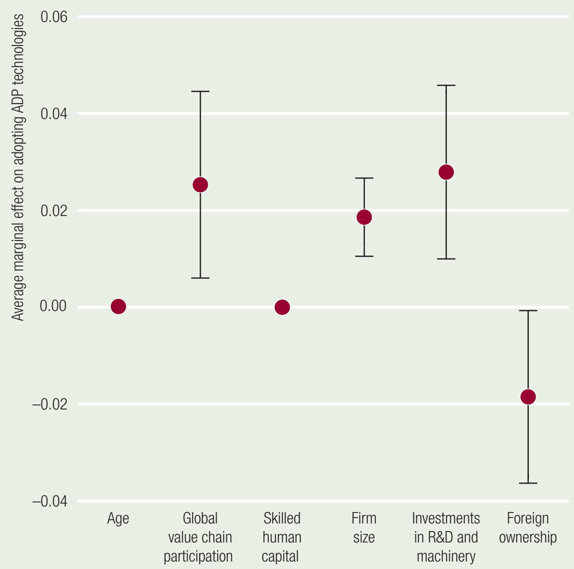
Manufacturing firms in developing and emerging industrial economies may depend on their integration in international trade and production networks for learning about new production technologies (Zanello et al. 2016). International trade and production

Participation in GVCs positively affects the probability of adopting advanced technologies

networks may offer viable channels for knowledge transfer to suppliers downstream in a GVC (World Bank 2017).

Data collected for this report also allow investigating the relationship between participating in GVCs and adopting new technologies in Ghana, Thailand and Viet Nam.[11] An econometric analysis of these data looked into the determinants of ADP technology adoption and found that participation in GVCs positively affects the probability of adopting most advanced technologies.[12] 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 (Figure 3.4). This finding supports the argument that integration within manufacturing GVCs can represent an opportunity for technological upgrading.

Figure 3.4
Firms participating in GVCs are more likely to adopt ADP technologies



Note: The graph depicts coefficients and confidence intervals (at 95 percent) for the average marginal effects of the variables of interest on the probability of belonging to the group of firms characterized by the highest generations of digital technologies (generations 3.0 and 4.0), rather than belonging to the other groups of firms (generations 1.0 and 2.0). An ordered probit model was implemented on firms surveyed in Ghana, Thailand and Viet Nam. 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 surveys "Adoption of digital production technologies by industrial firms."

The lack of funds, infrastructure and human resources are the main obstacles to advanced technology adoption

Why is adoption of ADP technologies still so low? The main barriers and limitations acknowledged by the firms surveyed generally included lack of funds (Figure 3.5). Half of firms in Ghana identified lack of funds as the main obstacle: this is not surprising given the limited access to credit in low- and middle-income countries. Firms in both Thailand and Viet Nam highlighted the lack of adequate human resources as a major obstacle: with more advanced industrial development, this result supports the argument that these countries need to reskill their labour force to foster the diffusion of new technologies. In Thailand, which has the highest rate of adoption of the most advanced generations of digital technologies (3.0 and 4.0) of the three countries, lack of awareness and time to recover investments are also important obstacles.

Small firms identify lack of funds as an obstacle

Obstacles cited by small and large firms differ. In Ghana and Viet Nam, a larger share of small firms identified the lack of funds as the main obstacle to adoption—almost 60 percent in Ghana and about 35 percent in Viet Nam. This is in line with small firms typically being more resource-constrained than larger ones.

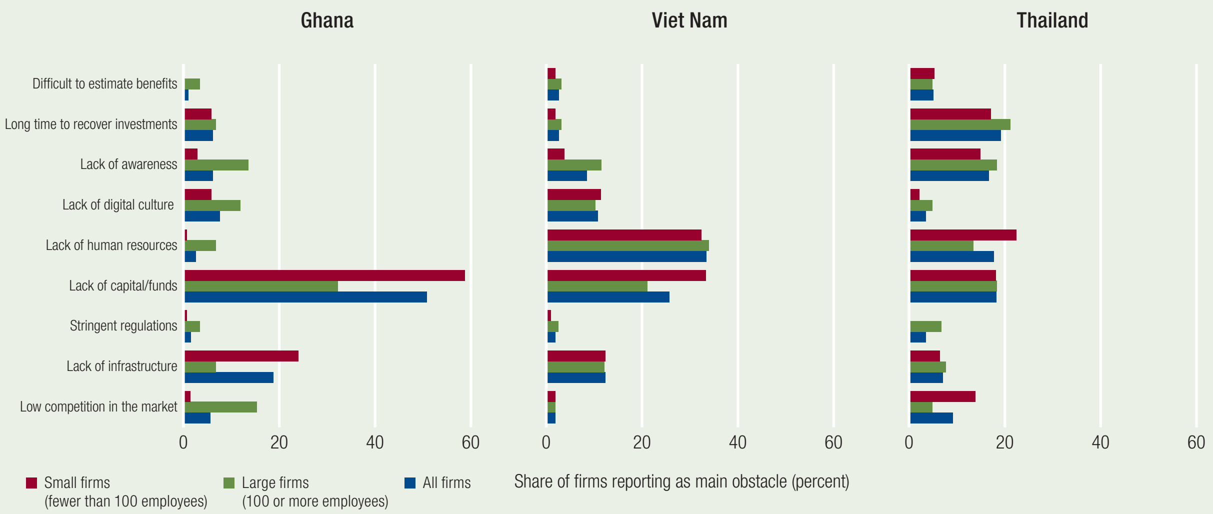
A dynamic approach to firm digital readiness

Expected technology adoption and efforts matter

The concept of a technological generation requires a time-related dynamic approach, covering not just which generation of technology a firm is actually using but, given the rapid process of change, what generation it foresees using. Moreover, although the progression from generation 1.0 to generation 2.0 does not require major organizational changes, a projected progression to generation 3.0 or 4.0 is not simple and linear but requires substantial changes in competences, production and organization. Even simpler digital solutions

> **Progression to generation 3.0 or 4.0 requires substantial changes in competences, production and organization**

Figure 3.5
The main obstacles to adopting ADP technologies reflect county-specific challenges



Note: For Argentina and Brazil no information is available on the main obstacles to the adoption of ADP technologies, due to the structure of their survey questionnaires. For each category, the figure shows the share of firms reporting it as the main obstacle to adopting ADP technologies (multiple answers not allowed). See Annex A.3 for more detailed information on sample composition and the methodology of the UNIDO survey.
Source: UNIDO elaboration based on data collected by the UNIDO firm-level surveys "Adoption of digital production technologies by industrial firms."

require changes in competences from analogue ones, demanding explicit learning efforts to upgrade firm capabilities. Thus, to assess firms' readiness for adopting further ADP technologies, the surveys for this report captured information on the technological generations a firm expects to use in the next 5–10 years and the firm's efforts to mobilize towards those levels.

The majority of firms in Argentina and Brazil expect to use advanced technologies in 5–10 years

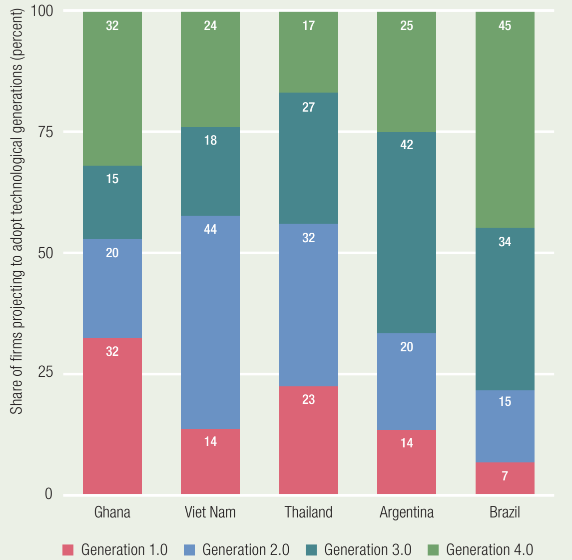
In all countries, the share of firms that expect to use the highest generations of digital technologies (generations 3.0 and 4.0) in the next 5 to 10 years increases dramatically (Figure 3.6). The highest projections are in Brazil, where 44.8 percent of firms expect to be at generation 4.0 and 33.5 percent at generation 3.0. In Argentina, 25 percent of firms expect to reach generation 4.0 (compared with only 2.9 percent at present —see Figure 3.1), and more than 40 percent to reach generation 3.0. A similar if less pronounced pattern emerges in Thailand and Viet Nam: 17 percent of firms in Thailand and 24 percent of firms in Viet Nam expect to reach generation 4.0. While in Thailand and Viet Nam, an increased share of users of generation 2.0 technologies replaces those currently using generation 1.0, in the Latin American countries, the share of generation 2.0 users decreases in favour of a larger share using higher technological generations (3.0 and 4.0). Ghana turns out quite different: 32 percent of firms expect to be at the most advanced generation 4.0 in 5–10 years. This proportion appears very large compared with the current 0 percent of firms at generation 4.0 in Ghana and also compared with the expected level of adoption of generation 4.0 in both Thailand and Viet Nam.

Are firms taking steps to upgrade technology?

The expected increase in ADP technologies appears to be good news. But since such expectations require developing adequate capabilities, they require concrete actions. Are firms actually making efforts to prepare themselves for the future, such as planning and implementing actions to achieve the projected goals? How ready are firms to adopt and absorb the latest production technologies and to reach the projected generation of digital technologies?

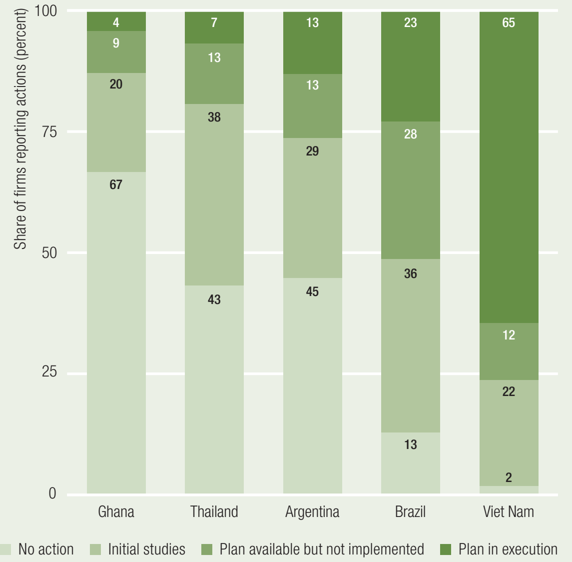
“A small proportion of firms are ready to leapfrog to the most advanced digital production technologies

Figure 3.6
Firms expect a marked increase in adopting ADP technologies in the next 5 to 10 years



Note: Countries are ordered according to the shares of firms currently adopting the highest generations of digital technologies (generations 3.0 and 4.0). See Annex A.3 for more detailed information on sample composition and the methodology of the UNIDO survey, including the definition of technological generations applied in the 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).

Figure 3.7
Many firms do not yet have plans available or in execution to achieve the highest technological generations in the next 5 to 10 years



Note: Data include only firms that expect to achieve technological generations 3.0 or 4.0 in the next 5 to 10 years. Countries are ordered according to the shares of firms having plans in execution. See Annex A.3 for more detailed information on sample composition and the methodology of the UNIDO survey, including the definition of technological generations applied in the 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).

The picture is mixed of firms’ steps to upgrade technology

Crossing the information about firms expecting to adopt the highest technological generations (generation 3.0 and 4.0) with the information about plans to achieve them produces a mixed picture (Figure 3.7). In Ghana, the projected technological level is not matched by plans or by actions. In Thailand and Argentina, similarly, most firms currently do not have plans or actions being executed. In Viet Nam, however, three quarters of firms expecting to use generations 3.0 or 4.0 have plans or are already implementing them. Brazil falls in between, with most firms having plans available or in execution.

Firms can be classified according to their digital readiness

The UNIDO Digitalization Readiness Index (DRI) was developed to estimate firm readiness for ADP technologies.[13] It summarizes how well a firm is equipped to face the challenges associated with digitalization and measures the firm’s technological dynamism. Inspired by Abramovitz (1986), the index assesses three categories of digital readiness. The most dynamic firms, classified as *forging ahead,* are currently endowed with the ADP technologies (generation 4.0) or are ready to leapfrog to them and have solid action plans in place. *Catching up* firms are in between: they intend to evolve from a low to a more advanced digital production technology, but their efforts are at an infant stage. *Lagging behind* firms currently adopt less advanced production technologies, have no plans of advancement or have plans not backed by concrete actions.

Few firms expect to leapfrog

Only a small proportion of firms are ready to leapfrog to the most advanced digital production technologies. Just

More technologically dynamic firms have higher capabilities

7.3 percent can be classified as forging ahead, 38.8 percent as catching up and 63.9 percent as lagging behind.

Each country has a unique digital readiness profile, and the differences among them are considerable (Figure 3.8). In Argentina, Ghana, Thailand and Viet Nam, the majority of firms belong to the lagging behind category. In Argentina and Viet Nam, the proportion of forging ahead firms is larger than in Ghana and Thailand. In Viet Nam, the share of catching up firms is larger than in Ghana and Thailand due to concrete plans for adopting more advanced technologies (see Figure 3.7). In Brazil, forging ahead and catching up firms represent the large majority, confirming that country's faster introduction of ADP technologies (see Figure 3.1).

Digital readiness and human capital

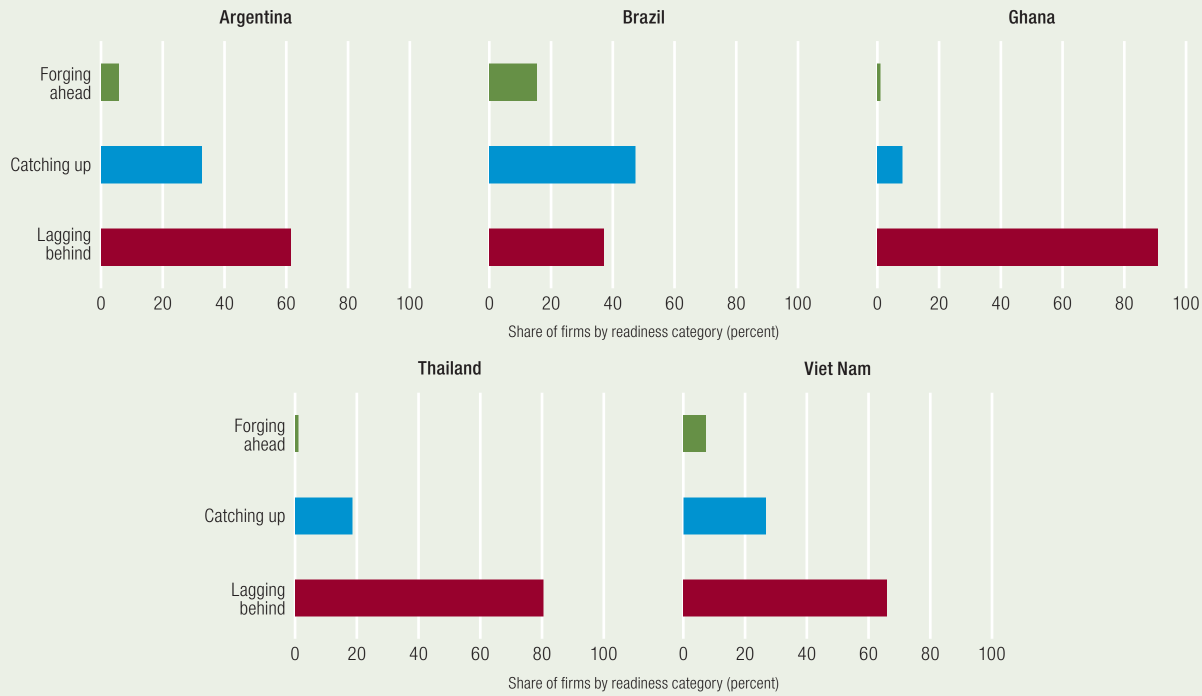
The more complex a digital solution, the more complex the capabilities required. Since the categories of digital readiness mirror the sophistication of firms' capabilities, they are expected to mirror firms' human capital composition.

Firms with higher technological intensity and larger firms have more STEM professionals

More technologically dynamic firms have higher capabilities. This is reflected in a larger share of STEM professionals[14] among firms in the forging ahead and catching up categories. The shares of STEM employees are systematically higher for these firms, regardless of country, size or sector (Figure 3.9).

Moreover, in all the countries considered, large firms on average have a higher share of STEM employees, consistent with their greater resources and higher capacity to recruit labour with more advanced and more specific qualifications. Since the need for employees with STEM qualifications can vary depending on

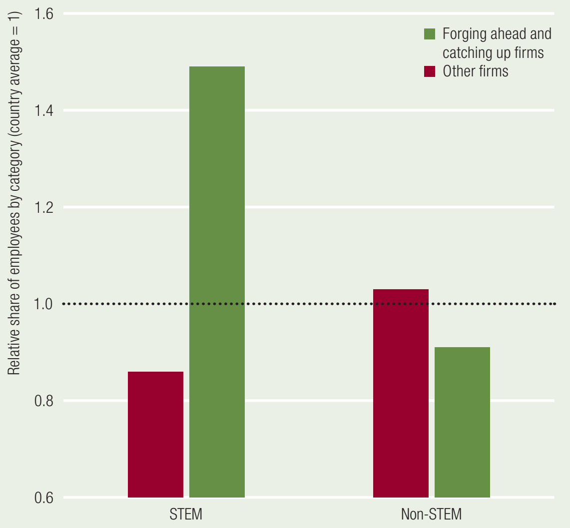
Figure 3.8
Few firms are ready to leapfrog to ADP technologies



Note: The figure presents the distribution of firms in three readiness categories (forging ahead, catching up, lagging behind) according to their score in the UNIDO Digitalization Readiness Index (DRI). See Annex A.3 for more detailed information on sample composition and the methodology of the UNIDO survey.
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).

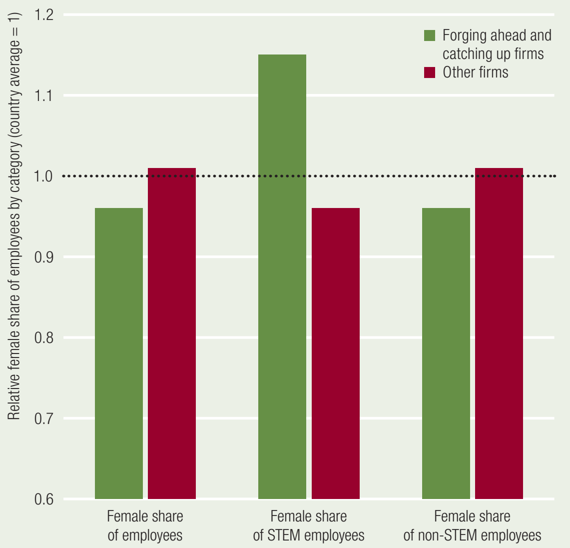
Forging ahead and catching up firms may create more opportunities for female STEM professionals

Figure 3.9
Firms in the forging ahead and catching up categories have a larger share of STEM employees



Note: STEM is science, technology, engineering and mathematics. Data refer to firms surveyed in Ghana, Thailand and Viet Nam. See Annex A.3 for more detailed information on sample composition and the methodology of the UNIDO survey.
Source: UNIDO elaboration based on data collected by the UNIDO firm-level surveys "Adoption of digital production technologies by industrial firms."

Figure 3.10
Firms in the forging ahead and catching up categories have a higher female share of employees with STEM qualifications



Note: STEM is science, technology, engineering and mathematics. Data refer to firms surveyed in Ghana, Thailand and Viet Nam. See Annex A.3 for more detailed information on sample composition and the methodology of the UNIDO survey.
Source: UNIDO elaboration based on data collected by the UNIDO firm-level surveys "Adoption of digital production technologies by industrial firms."

the firm's main activity, firms operating in TDI industries display higher shares of STEM employees.

Increasing women's equitable participation is necessary to promote inclusive and sustainable industrial development
UNIDO recognizes the importance of a comprehensive debate on the relationship between gender and advanced production technologies in manufacturing. As discussed in Chapter 2, increasing women's equitable participation in the industrial workforce is necessary to promote inclusive and sustainable industrial development (ISID, UNIDO 2019d). With evidence from developing countries particularly scarce, the survey data collected for this report provide new and original inputs for a more evidence-based discussion.

Some general patterns of female employment emerge (Figure 3.10).[15] The share of female employees tends to be on average lower in forging ahead and catching up firms. Although this result may confirm the gender segregation of the labour market, where female workers are less likely to be hired by the most technologically dynamic firms, those firms tend to employ a larger share of female employees with STEM qualifications. Thus, firms that are classified as forging ahead and catching up may create more opportunities for female STEM professionals by offering better jobs for more qualified women.

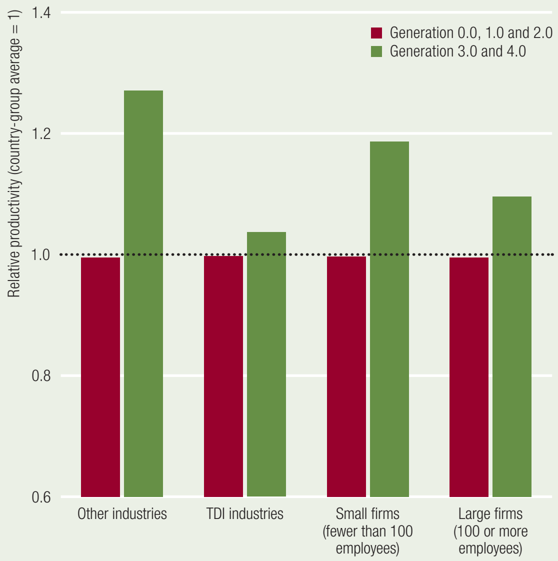
Implications of ADP technologies

Productivity

Firms adopting advanced technologies have higher productivity
Firms adopt new technologies mostly due to expected gains in competitiveness and efficiency (see Chapter 1). The UNIDO survey data confirm that firms adopting advanced technologies enjoy a higher level of productivity (Figure 3.11). This result holds across countries, and controlling for firm size and sector: large firms and firms belonging to TDI sectors using the highest generations of digital production technologies (3.0 and 4.0) enjoy a higher level of productivity, but so do

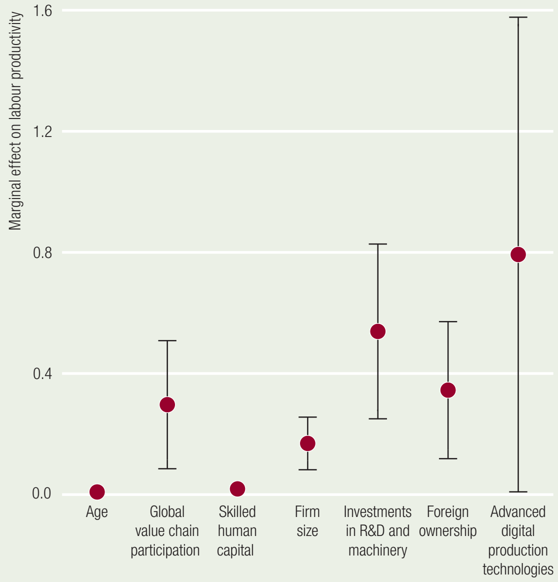
“Adoption of ADP technologies was positively and significantly associated with firm productivity

Figure 3.11
Across sectors and sizes, firms adopting ADP technologies display higher productivity



Note: TDI is technology- and digital-intensive. Data refer to firms surveyed in Ghana, Thailand and Viet Nam. The figure shows the difference in average productivity level for all firms in the country and by industry and firm size. TDI industries include automotive and auto parts, and electronics. Other sectors include food and beverages; textile, leather and footwear; plastic and rubber; metal products; and wood and furniture. See Annex A.3 for more detailed information on sample composition and the methodology of the UNIDO survey, including the definition of technological generations applied in the survey questionnaires.
Source: UNIDO elaboration based on data collected by the UNIDO firm-level surveys “Adoption of digital production technologies by industrial firms.”

Figure 3.12
The adoption of ADP technologies is associated with productivity more strongly than other firm characteristics are



Note: The graph depicts the coefficients, with confidence intervals (at 90 percent), of the variables of interest with labour productivity, obtained through 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 generation 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 surveys “Adoption of digital production technologies by industrial firms.”

small firms and those belonging to other sectors when they adopt these technologies. The positive firm-level relationship confirms what was found at the aggregate level, where a higher diffusion of ADP technologies is associated with better country-level economic performance (see Figure 1.18 in Chapter 1).

The technology–productivity relation holds regardless of human capital and GVC participation

A further econometric analysis investigated whether firms with a higher level of digitalization in production were, on average, more productive when controlling for other factors. The intensity of adoption of ADP technologies was positively and significantly associated with firm productivity, even when controlling for a firm’s age, investments in R&D and machinery, human capital and GVC participation. Technology adoption’s coefficient is large compared with the coefficients of other significant factors (Figure 3.12).[16]

Organization of global production

ADP may also increase asymmetries between actors in developed and developing countries

Despite the hype about their potential, advanced industrial technologies should arouse caution and calls for moderation (European Commission 2016, OECD 2017). In Chapters 1 and 2, changes in the labour markets, barriers to access to the technologies and an eventual increased market concentration were identified as the main drawbacks. For firms participating in GVCs, threats from supply chain reorganization, delocalization of production and backshoring must be added. As argued by Mayer (2018), digitalization may be ambivalent if it increases asymmetries between actors in developed and developing countries.

> **Firms in developing countries may be harmed by the progressive diffusion of ADP technologies in advanced economies**

Digitalization could increase oligopoly and power concentration in GVCs

Firms in developing countries may be harmed by the progressive integration of ADP technologies into GVCs if they increase barriers to access. As the increased digital integration of systems through software platforms affects the structure of GVCs, concerns arise about coordination and governance mechanisms, possibly increased concentration of power and more oligopolistic and monopolistic market settings in fully digitalized supply chains (Andreoni and Anzolin 2019).

ADP technologies could foster backshoring

Firms in developing countries may also be harmed by the progressive diffusion of ADP technologies in advanced economies. For advanced countries, the earlier drawbacks of lost manufacturing jobs could be softened by the expectations that ADP technologies may bring production back (backshoring or reshoring) and reboost manufacturing production. 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. For developing countries, the lost relevance of cheap labour as a comparative advantage and the increased backshoring to industrialized countries could take away manufacturing and reduce employment creation (Rodrik 2018).

Not much backshoring is evident

Beyond hypotheses and anecdotal examples, general evidence of actual 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 using European Manufacturing Survey data (EMS 2015) of firms for eight European countries (Austria, Croatia, Germany, the Netherlands, Serbia, Slovenia, Spain and Switzerland) analyses the extent and determinants of backshoring.[17] The sample is composed of about 2,500 firms of different sizes. Three findings clearly 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 firms backshore from emerging economies, but it is important in backshoring from other high-income countries (Figure 3.13). 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 certain sectors (chemical industry, machinery, electrical industry or transport equipment —rather than low-technology sectors) and for firms more intensively adopting advanced digital technologies. So, adopting ADP technologies might prompt backshoring, though not frequently.

Environmental sustainability

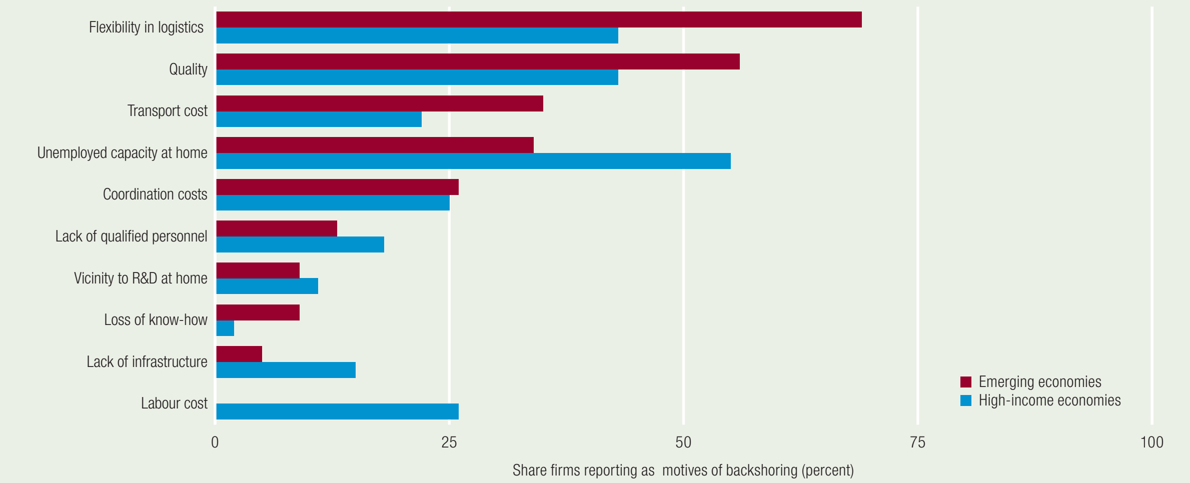
Technological change may benefit the environment. A previous edition of the UNIDO IDR showed that high-income countries tended to be more environment-friendly than low-income countries in energy intensity (UNIDO 2011) and possess more environment-friendly technology.

Technologically dynamic firms are optimistic about environmental improvements

In Ghana, Thailand and Viet Nam, in all environmental domains—water, energy, materials and waste—the majority of firms in the forging ahead and catching up categories agree that ADP technologies can lead to environmental improvements leading to efficiency and productivity gains (Figure 3.14). Waste management is complex, with different approaches from the least to the most environment-friendly represented by waste minimisation[18]. The IDR 2018 pointed out that efficiency and productivity increases could bring reduced prices and increased demand (UNIDO 2017c). Efficient use of

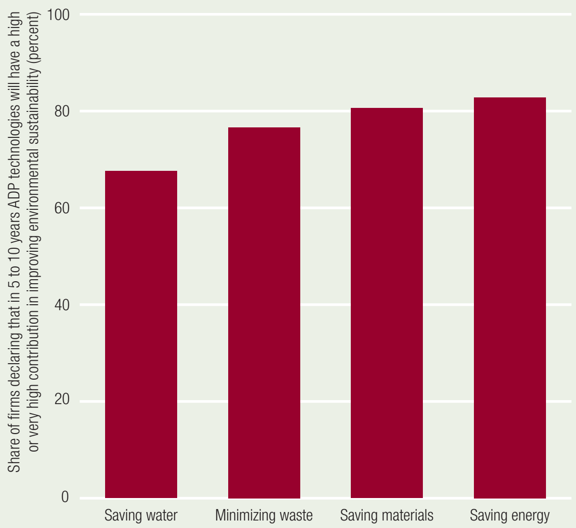
“Adopting ADP technologies might prompt backshoring, though not frequently

Figure 3.13
Flexibility was the main motive of backshoring from emerging economies in 2013–2015



Note: The survey, conducted in 2013–2015, included 2,448 European firms with at least 20 employees from Austria, Croatia, Germany, the Netherlands, Serbia, Slovenia, Spain and Switzerland. Only firms engaged in backshoring are considered. Multiple answers are allowed.
Source: Dachs and Seric (2019), based on the European Manufacturing Survey (EMS 2015).

Figure 3.14
The majority of firms in the forging ahead and catching up categories agree that ADP technologies will lead to environmental improvements



Note: Data refer to firms surveyed in Ghana, Thailand and Viet Nam and include only firms classified as forging ahead and catching up. See Annex A.3 for more detailed information on sample composition and the methodology of the UNIDO survey.
Source: UNIDO elaboration based on data collected by the UNIDO firm-level surveys “Adoption of digital production technologies by industrial firms” and Kupfer et al. (2019).

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.

Employment and skills

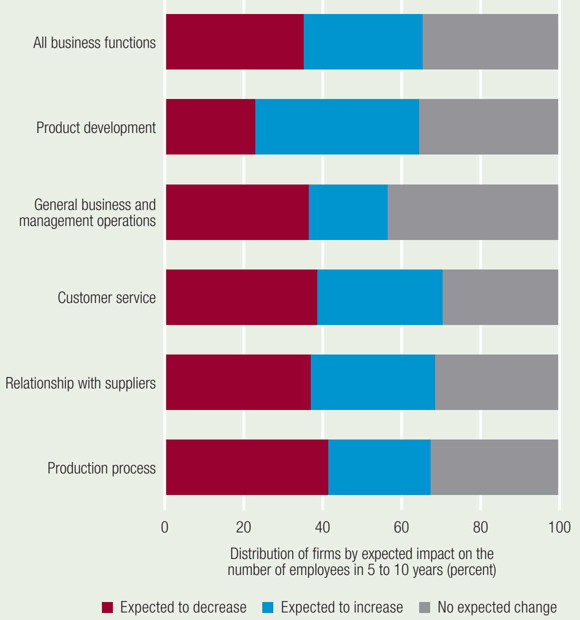
The impact of ADP technologies on employment tends to be controversial (Chapters 1 and 2). Whereas the policy debate stresses the risk of displacing labour with digital technologies, this report emphasizes the mechanisms by which new technologies can boost employment rather than reducing it. The report offers innovative insights on the possible complementarity of ADP technologies and labour—for instance, the introduction of robots can stimulate forward and backward linkages (Chapter 2).

Technologically dynamic firms anticipate stable employment

The survey data collected show that firms in the forging ahead and catching up categories expect to keep the same level of employment or even increase it as a consequence of ADP technology (Figure 3.15). This holds in all the business functions of firms in

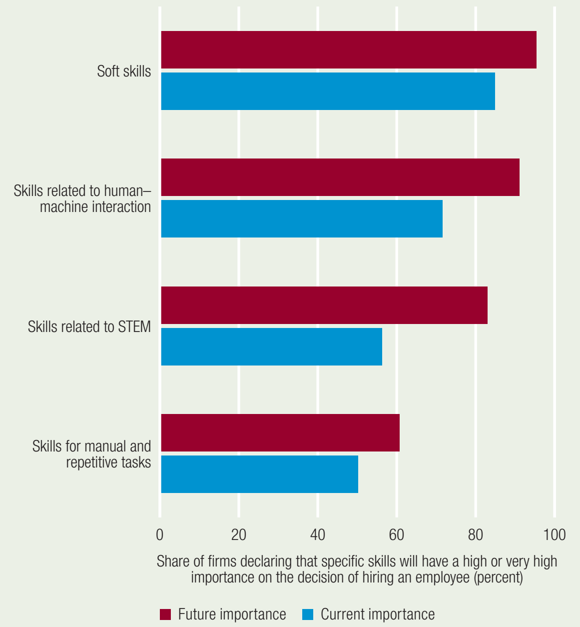
> **Soft skills are projected to become very important, according to almost all technologically dynamic firms**

Figure 3.15
The majority of firms in the forging ahead and catching up categories expect to increase or keep the same number of employees as they adopt ADP technologies



Note: Data refer to firms surveyed in Argentina, Ghana, Thailand and Viet Nam and include only firms classified as forging ahead and catching up. See Annex A.3 for more detailed information on sample composition and the methodology of the UNIDO survey.
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).

Figure 3.16
The majority of firms in the forging ahead and catching up categories agree that soft skills are expected to be very important in future hiring



Note: STEM is science, technology, engineering and mathematics. Data refer to firms surveyed in Argentina, Ghana, Thailand and Viet Nam and include only firms classified as forging ahead and catching up. See Annex A.3 for more detailed information on sample composition and the methodology of the UNIDO survey.
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).

Argentina, Ghana, Thailand and Viet Nam. The findings also robust across countries and firm size.

Technologically dynamic firms emphasize skills related to STEM, human–machine interaction and soft skills

But ADP technologies are also changing the nature of employment. The survey data collected show that the job market increasingly emphasizes STEM-related skills and human–machine interaction. Skills required for routine activities will be less relevant than other skills. Surprisingly, soft skills are projected to become very important according to almost all technologically dynamic firms (Figure 3.16). The reason may be that many new technologies promise to require employees to work as well-integrated teams and to learn procedures and systems rapidly. As seen in Chapter 2, the gender gap in soft skills is smaller than the gap in analytical skills. Thus, women could take this job market trend favouring soft skills as an opportunity, aligning with men on soft skills more easily than on STEM or other analytical skills.

Getting the most out of it: Capabilities for industrializing in the digital age

Building production capabilities through industrial experience

Production capabilities represent firm manufacturing learning

As discussed at the beginning of this chapter, capabilities can broadly be divided into investment and

“ Production capabilities increase innovation performance

technology capabilities (for skills, R&D, capital expenditures and national innovation systems) and production capabilities (expectations and behavioural factors) (Table 3.3). The production capabilities represent learning from repeated operations within the firm, and they are correlated with past success, experience and managerial skills and behavioural factors. Variables representing previous success (patents, exports) capture the accumulated learning. Managerial experience and behavioural intentions explain the adoption of technology because they proxy the soft skills needed to implement change in organizations and production. Production capabilities are thus intrinsically related to introducing and developing industrial processes with technological content.

The policy debate should focus on production capabilities

The policy debate so far has focused mostly on investment and technology capabilities. Although those capabilities are relevant for ADP technologies uptake, this report shows that policy should pay more attention to production-related aspects and associated production capabilities. An analysis of 13 African countries and four South Asia countries[19] using the World Bank Enterprise Survey concluded that production capabilities are the most important determinant in adopting new technological process innovations (Figure 3.17).[20]

Combined, investment and technology and production capabilities lead to innovation

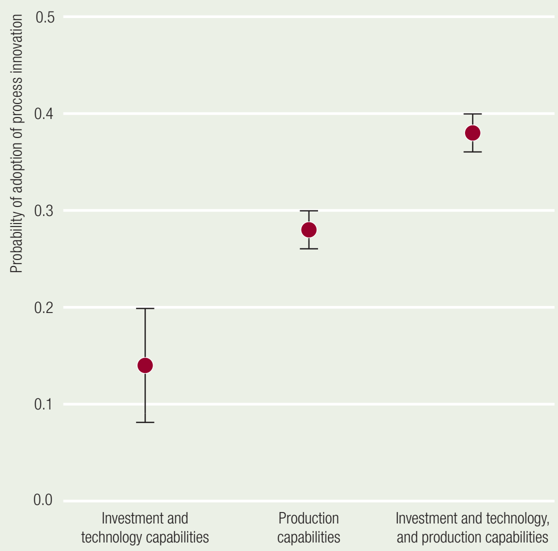
This does not mean that investment and technology variables did not matter in the analysis. While production capabilities are always important for adopting technological process innovations, investment and technology capabilities fully disclose their importance when combined with production capability variables. Firms where both investment and technology, and production variables were operational had a higher probability of adopting new processes than firms where only one kind of variable was active.

Table 3.3
Investment and technology and production capabilities

Investment and technology capabilities	Production capabilities
Acquired through market or other institutions—for example, human capital, R&D expenditure, information received through markets or other institutions of the national system of innovation	Produced by learning inside the firm and correlated with past success (exports, past innovations), experience and managerial skills and behavioural factors (intention to innovate, expectations)

Source: Bogliacino and Codagnone 2019.

Figure 3.17
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, Tanzania, Uganda, Zambia and Zimbabwe) and 4 South Asian economies (Bangladesh, India, Nepal and Pakistan). Only manufacturing firms are included. 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 the World Bank Enterprise Survey (Innovation Follow-up, 2013–2014).

Production capabilities explain the importance of earlier industrial experience to innovation

The importance of production capabilities is somewhat surprising, given the attention the literature has traditionally dedicated to technology variables in explaining technological change. This finding has implications for other findings of this report (see

> **Production capabilities have to be built up before moving into high innovation activities**

Chapter 1) and supports the idea of industrialization as an engine of growth. If production capabilities are intrinsically related to introducing and developing industrial processes with technological content and to consequent technological and production learning, technology is an opportunity found where industrialization has already happened.

Production capabilities help firms both with and without human capital and R&D

The message is twofold. Production capabilities are key: experience, previous success and the accumulated knowledge base are crucial to generating the enabling conditions to innovate and adopt new production technologies. Moreover, both for firms that lack investment in human capital and R&D, and those that have it, production capabilities increase innovation performance. Thus, despite being critical, technological integration in itself may not be sufficient to deliver the productivity gains from ADP technologies. The problem many companies in developing countries face is that deploying integrated technologies requires advanced capabilities for production and organization. In line with the approach of the capability roadmap presented in Table 3.1, production capabilities have to be built up before moving into learning processes and high innovation activities. But emerging countries appear to be following a well-established technology-first trajectory, suggesting that the technological gap is likely to persist.

Digitalization and innovation

Digitalization and innovation enable the adoption of ADP technology

Do firms in developing countries have a comprehensive set of investment, technology and production capabilities enabling them to adopt ADP technology? This section focuses on digitalization and innovation using data from the World Bank Enterprise Surveys on 11 African countries and four South Asian countries.[21] It distinguishes firms with different degrees of capabilities, differentiating their ability to move towards industrial digitalization. The analysis helps identify the current capabilities of developing country firms, their position in the hierarchy of technological competences, the extent of their digital activities and their potential for becoming full players in ADP technologies.

Highly innovative firms may be candidates for the uptake of ADP technologies

Four categories of firms—digital leading firms, highly innovative firms, product innovation firms and noninnovating firms—can be distinguished (Table 3.4). Digital leading firms are characterized by strict digital criteria and innovation activities, reflected in the presence of product innovation, process innovation, automation and R&D expenditures. These activities show the presence of the investment, technology and production capabilities discussed above. Given their capabilities, these firms may be in a position to adopt advanced production technologies. Highly innovative firms are characterized by innovation activities such as product and process innovation, R&D investment and some dimensions of digitalization. Highly innovative

Table 3.4
Characteristics of firm categories

Firm categories	Characteristics
Digital leaders	Product innovation Process innovation Automation R&D expenditures Digital characteristics: (1) presence of employees using computers, (2) purchase or in-house development of software, (3) presence of employees working on information technology, (4) use of computer consultants, (5) use of internet for all business activities
Highly innovative	Product innovation Process innovation Automation R&D expenditures
Product innovators	Product innovation
Noninnovators	

Source: Pianta 2019.

> **Digital firms are a niche in developing countries**

firms may also be good candidates to adopt new technologies, since they display the technology capabilities needed to prepare to use more advanced technologies.

Digital firms are a niche in developing countries

The group of digital leaders is not large in the considered sample countries. But in digital leader firms, there is a strong relation between capabilities and performance.

Digital leaders in India generate high exports and sustain employment

The experience of India—a country actively engaging with ADP technologies (see Chapter 1)—can demonstrate the relationship between digitalization and various performance measures (Figure 3.18). The digital leading firms and the highly innovative firms are better represented in the TDI industries and have the highest share of exporting firms and highest level of exports per capita. More innovation and digital activities are associated with higher employment generation, while less innovative firms consistently are less present in digital industries and create less employment. Innovation and digitalization are not necessarily associated with lower employment: the majority of digital leading and highly innovative firms are experiencing an increase of skilled employment. And the digital leading firms are also experiencing an increase of unskilled employment. Even so, technological change could be negatively affecting employment, if that negative effect were being counterbalanced by demand effects increasing production and thus employment demand.

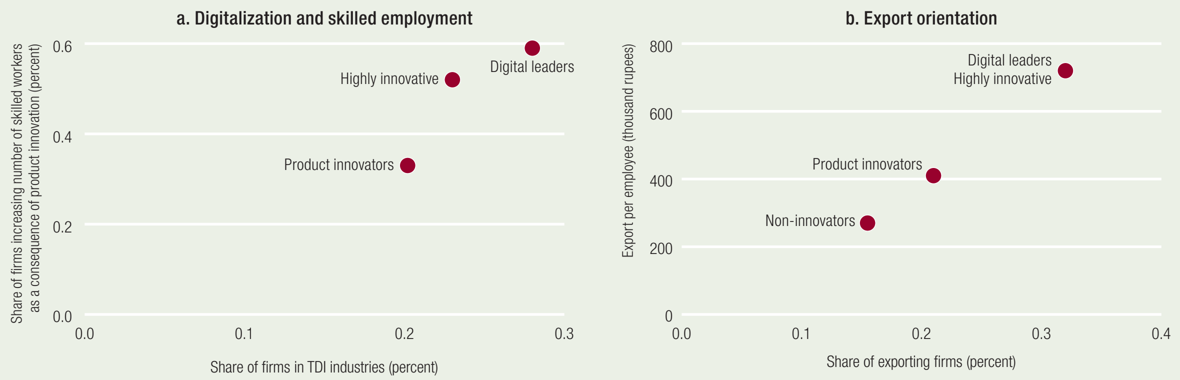
Firms' classification mirrors their technological and production hierarchy

The classification of firm categories appears to solidly represent the technological and production hierarchy of firms (Table 3.5), showing how they have taken a first step. The results of the analysis reinforce the need for a mix of production and investment and technology capabilities in order to upgrade.

Some top industrial firms are becoming top digital firms

Digital leading firms, the élite of technological players, comprise between 0.1 percent and 3.0 percent of firms in considered countries (see Table 3.5). Thus only a few firms in each country fall in this group. Some firms in the emerging and developing countries are now moving from being top performers in industrial production capabilities to entering the club of top firms in technological and digital capabilities. A

Figure 3.18
Digital leaders show a better performance in terms of presence in TDI industries, export and employment generation



Note: TDI is technology- and digital-intensive. Data include only manufacturing firms in India. TDI industries include machinery, electronics and information and technology services.
Source: Pianta (2019) based on World Bank Enterprise Survey (Innovation Follow-up, 2013–2014).

> **Manufacturing tends to be the key sector for innovation**

Table 3.5
Share of firm categories in 15 developing countries

Country	Digital leaders	Highly innovative	Product innovators	Noninnovators
Bangladesh	0.70	15.91	46.32	37.08
Congo, Dem. Republic of	0.55	10.38	30.60	58.47
Ghana	0.35	7.80	18.79	73.05
India	1.69	16.81	50.33	31.17
Kenya	0.71	11.39	33.45	54.45
Malawi	2.99	20.90	35.82	40.30
Namibia	0.00	15.87	31.75	52.38
Nepal	0.43	2.13	14.47	82.98
Nigeria	0.75	9.95	27.36	61.94
Pakistan	0.00	2.07	22.63	75.30
South Sudan	1.22	6.10	63.41	29.27
Sudan	1.06	5.32	32.98	60.64
Tanzania, United Republic of	0.00	0.74	17.65	81.62
Uganda	2.88	9.13	44.71	43.27
Zambia	0.00	15.30	45.15	39.55

Note: Only manufacturing firms are included.
Source: Pianta 2019.

rigorous selection for that club, however, appears to require not just strong efforts by individual firms but also a national system able to support the technological upgrading of enterprises, including a large country size, a diversified industrial base with strong manufacturing capabilities, well-functioning institutions and educational and public policy systems.

16 percent of firms in India and Bangladesh are classified as highly innovative

Highly innovative firms appear to be a relevant share of firms in several developing countries: 17 percent in India, 16 percent in Bangladesh, 11 percent in Kenya and 10 percent in Nigeria. And some African countries have fairly high shares. Product innovators range between 50 percent in India to 46 percent in Bangladesh, 33 percent Kenya, 27 percent in Nigeria and 23 percent in Pakistan, while high shares are also found in some African countries. Noninnovators range from 83 percent in Nepal to 31 percent in India. Overall, the potentially highly performing firms characterized by strong capabilities—the digital leaders and highly innovative firms—is a minority.

The manufacturing sector has the lion's share of technologically advanced firms

Manufacturing tends to be the key sector for innovation, though the analysis also includes service industries. In India, 88 percent of all firms belonging to the digital leaders group are in the manufacturing sector, in Nigeria, 75 percent and in Kenya, 50 percent. In India 94 percent of highly innovative firms are in manufacturing, in Pakistan, 92 percent and in Kenya, 58 percent. This result is hardly surprising: as the IDR 2016 showed, the manufacturing sector normally has higher levels of R&D and innovation expenditures. This has traditionally been considered a key explanation in the academic and policy debate of manufacturing's prominence as an engine of economic growth (Kaldor 1961).

Mostly—but not only—large firms

Digital leaders are not necessarily large firms. Large firms are conspicuously associated with frontier technology because they can afford high levels of R&D expenditures, have more experience and can more easily form partnerships or prompt government

> **Smaller firms can share in new technology adoption if they find digital niches connected to expanding markets and GVCs**

interventions. Large firms are also important for innovation in developing countries, where the economic structure tends to be more polarized than in advanced economies (Pianta 2019). In India, 60 percent of digital leaders are large enterprises with more than 100 employees, according to World Bank Enterprise Survey results. Such results are consistent with those reported above highlighting the leading role of large firms in ADP adoption. But in all countries, a few SMEs occupy niches of digital success. So, smaller firms can share in new technology adoption if they find digital niches connected to expanding product markets and GVCs guided by dynamic large firms.

Notes

1. This section is based on Andreoni and Anzolin (2019).
2. Systemic capabilities (or social capabilities) include a broad range of context-specific factors, such as regulations and institutions, a financial system, knowledge creation and education networks and infrastructure (Abramovitz 1986).
3. The case studies are presented in Calza and Fokeer (2019). See Chapters 1 and 2 of this report for Boxes with more details on specific firms.
4. This section is based on Albrieu et al. (2019) and Kupfer et al. (2019). See Annex A.3 for details of surveys and their methodology.
5. The questionnaire used is based on the one applied in Brazil in 2017 by the National Confederation of Industry (CNI) and replicated in Argentina in 2018 by Inter-American Development Bank Institute for the Integration of Latin America and the Caribbean (BID-INTAL) in cooperation with Centre for the Implementation of Public Policies Promoting Equity and Growth (CIPPEC) and the Argentine Industrial Union (UIA). More information on the definition of generations of digital technologies used in the survey questionnaires are reported in Annex A.3.
6. For Argentina and Brazil, no information on generation 0.0 are available, due to the slightly different structure of the survey questionnaire. It is to be expected that the share of firms using only analogue technologies should be lower, given the average diffusion of higher technological generations.
7. Ghana is excluded from the comparison because the Ghanaian sample does not include any firm in TDI industries.
8. Moreover, interindustry differences are present across all technological generations, and not only in the most advanced ones. In other sectors in all considered countries, a higher share of firms use generation 1.0.
9. Since the Brazilian sample includes only large firms with 100 or more employees, Brazil is excluded from the comparison.
10. The share of small firms using generation 1.0 is much larger than the share of large firms. But in Ghana, Thailand and Viet Nam, large firms tend to use generation 2.0 technology more.
11. Information on GVC participation was collected only in Ghana, Viet Nam and Thailand. More details on topic coverage of individual country surveys are reported in Annex A.3.
12. For full results, see Pietrobelli et al. (2019).
13. The methodology of the Digitalization Readiness Index (DRI) is explained in Annex A.3.
14. The survey conducted for this report asked firms about the number of employees with university or college degrees who are poly-scientific professionals, as in natural sciences, physics, engineering or biological sciences. For simplicity, these employees are called STEM employees.
15. These figures on female employment confirm the larger female participation of women in formal labour markets in Thailand and Viet Nam: in surveyed firms around 50 percent of employees are women. However, female participation varies largely across countries: in Ghana it is around 30 percent. The lower share in Ghana may reflect the widespread informality of the economy, which would tend to draw most female workers into informal occupations.

16. Caution in interpreting this result is, however, necessary, as the coefficient of the variable "Advanced digital production technologies" is significant at 10 percent.
17. See Dachs and Seric (2019) for the details of this analysis.
18. According to OECD (2000) waste minimization is "Preventing and/or reducing the generation of waste at the source; improving the quality of waste generated, such as reducing the hazard, and encouraging re-use, recycling, and recovery."
19. The Democratic Republic of Congo, Ghana, Kenya, Malawi, Namibia, Nigeria, Rwanda, Sierra Leone, South Sudan, Sudan, the United Republic of Tanzania, Uganda, Zambia and Zimbabwe in Africa and Bangladesh, India, Nepal and Pakistan in South Asia.
20. See Bogliacino and Codagnone (2019) for details about this empirical analysis.
21. This section is based on Pianta (2019).

Chapter 4

Responding to advanced digital production technologies

Few economies possess the required foundation of technological and manufacturing capabilities

As the ongoing technological and productive transformations commonly associated with the fourth industrial revolution (4IR) continue to unfold, often in uncertain directions, few economies, particularly developing ones, possess the required foundation of technological and manufacturing capabilities to even attempt to lead the development of advanced digital production (ADP) technologies and smart manufacturing production. Differences in capabilities across countries, sectors and firms suggest that the individual ability to respond to challenges, and to capitalize on emerging opportunities, is uncertain—and a concern for countries where minimum conditions for industrialization are yet to take root. The systemic nature of the recent innovation dynamics—and of the impacts that can be associated with each of the technologies, or with combinations of them—will continue to challenge policy-makers, businesses and academics for many years to come.

A capability-building approach helps to understand strategic responses

In line with the general thrust of this report, this chapter adopts a capability-building approach to understand how strategic responses address distinct but interconnected policy areas—from manufacturing through innovation and education, to infrastructure and even international collaboration. The assumption is that different countries respond differently, according to their accumulated capabilities, exposure and experience with manufacturing (UNIDO 2002, 2005, 2015). While the chapter focuses on developing countries, it draws selectively from industrialized countries' experiences to contrast them with developing countries'.

National strategy documents signal efforts to build readiness

Coordinated strategic responses are essential to identify and tackle opportunities that stem from ADP technologies (Lee et al. 2019). National strategy documents signal, at least on paper, efforts to build readiness for the ongoing technological and productive transformations. The documents can provide a frame of reference in time and space—whether for a country, region, industry or firm—for actions to foster the momentum and effective implementation of smart manufacturing solutions and tools. Building on evidence from strategic documents, roadmaps and white papers, this chapter distils some general policy lessons that countries should take into account to make ADP technologies work for inclusive and sustainable industrial development (ISID).

Be wary of one-size-fits all solutions

A key message for policy-makers: Be wary of one-size-fits-all solutions. Despite the diversity of approaches to smart manufacturing in both developed and developing countries, 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 systematic evaluations to inform recommendations are still pending.

Remember that it takes commitment and substantial resources to develop capabilities

Policy-makers, particularly in developing countries, should remember that it takes commitment 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.

> **Different countries respond differently, according to their accumulated capabilities and exposure and experience with manufacturing**

Characterizing strategic responses to ADP technologies

Trends underpinning the 4IR are expected to deepen

Since the trends underpinning the 4IR are expected to deepen in coming years, countries at different stages of development are waiting to pursue them as they launch their roadmaps or full-fledged 4IR-inspired development strategies. Given this state of flux, it seems pertinent to review and discuss the trails followed and the decisions made by early adopters, while providing some useful leads to those policy-makers still grappling with questions about how to initiate their march towards 4IR.

Multistakeholder and participatory approaches are key

The discussion aims to provide a minimum of guidance to those responsible for developing strategic responses to the challenges of ADP technologies applied to manufacturing—smart manufacturing production—with emphasis on elements of design, strategy formulation and implementation. What drives the preparation of such strategies? And how have they come into being? A key insight here is the greater importance of multi-stakeholder and participatory approaches. The evidence suggests diverse concrete measures and tools deployed when implementing national strategies, and the approaches to follow and assess progress are equally diverse.

International collaboration and policy coordination can support developing countries

The review of national strategies informs initiatives to support capability building of firms—particularly small and medium-sized enterprises (SMEs)—and particularly people. And in the spirit of United Nations Sustainable Development Goal (SDG) 17 "Partnerships for the goals," the chapter illustrates how international collaboration and policy coordination can support developing countries' continued quest for industrialization in the new era of smart manufacturing.

National strategies reflect the extent of industrialization and capability accumulation…

Strategic responses to smart manufacturing are mixed

Strategic responses to smart manufacturing 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 the national priorities and capacities to mobilize public-private partnerships. The possibility for mixed strategies within a single country results in a complex policy space characterized by "twin policy problems" along a continuum: At one end are policies to sustain global manufacturing leadership—and at the other are interventions to cope with risks or, at best, create conditions for followers and latecomer agents to adapt and catch up (Figure 4.1). (See Annex A.4 for summaries of 11 countries' plans and strategies.)

Frontrunners strive to forge ahead

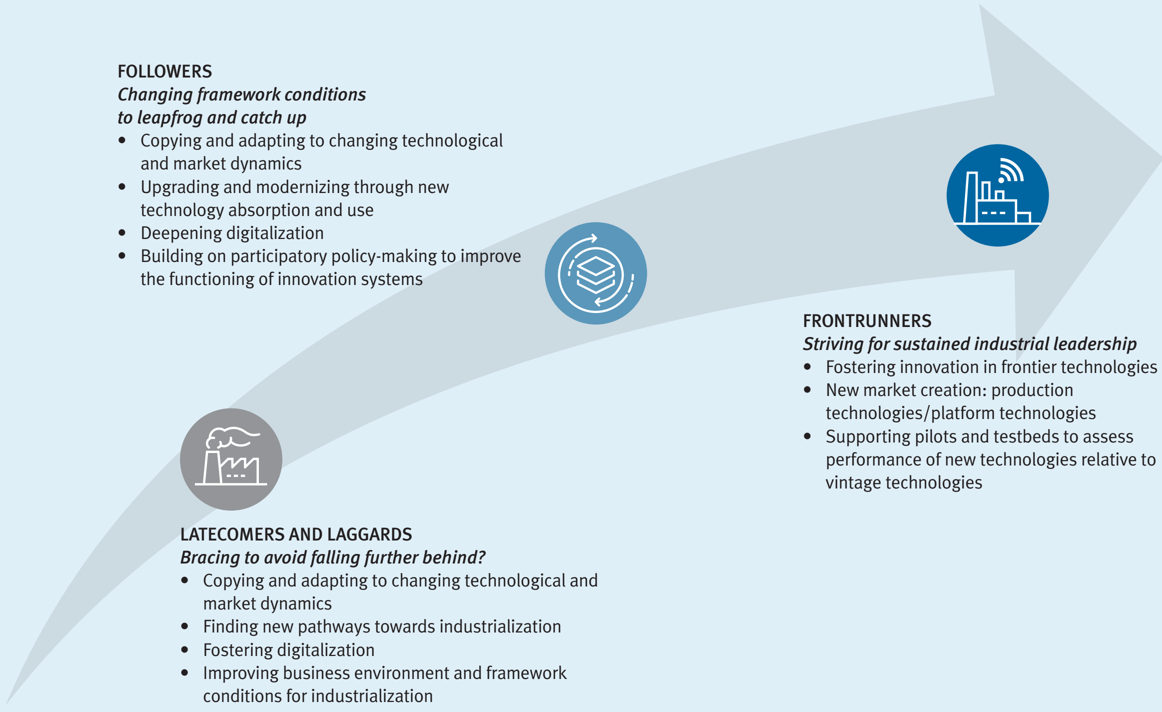
Strategic responses reflect differences in the size of the economy and domestic markets, the strength of domestic manufacturing, the adoption of industrial automation and the means to achieving intended objectives. For frontrunners (see Chapter 1), policies to sustain or regain industrial leadership (Santiago 2018, Santiago and Horst 2018) and to pursue economic, social and environmental goals are common (Digital Transformation Monitor 2017, Liao et al. 2018). These countries generally intend to use ADP technologies and related concepts as drivers of economic transformation and to remain at the frontier of technological and industrial capabilities (Box 4.1).[1]

China quickly joined the frontrunners

Whereas highly industrialized economies tend to dominate the frontrunner category, China—a recent graduate to middle-income status—is an exception. It joined the frontrunner group rapidly, steadily

Followers aspire to foster innovation-driven development

Figure 4.1
Strategic responses reflect differences in manufacturing development across countries



Source: UNIDO elaboration.

Box 4.1
Highly industrialized economies differ in their strategic stances for smart manufacturing

A pioneer in adopting advanced digital production (ADP) technologies—under the label Industry 4.0—as a policy-guiding concept, Germany is building on its cumulated technological and industrial capabilities to tackle challenges associated with rising labour and energy costs, infrastructure-modernizing demands and skill shortages (Pfeiffer 2017). In addition to becoming a lead producer of ADP solutions and technologies, it hosts several major players in the field. The country's strategy has been characterized as simultaneously defensive, to maintain home-based production and increase flexibility to respond to crises in international markets—and offensive, to retain skills and know-how to support an export-led model (Blanchet et al. 2016).

Confronted with an aging and declining industrial base, France pursues resurgence through enhanced digitalization and virtualization. It also promotes a growing start-up ecosystem to renew the domestic manufacturing base and reposition itself as industry leader, subject to its ability to offset labour costs and related social constraints (Blanchet et al. 2016).

Source: UNIDO elaboration.

changing its approach to industrial development from catching up to capitalizing on its increased ability to (re)produce new advanced technologies, add value and enhance technological content, superseding the traditional cost advantage strategy (Li 2018). China seeks to upgrade within value chains, while exploring new development paths building on decades of systematic and sustained accumulation of technological and productive capabilities.

Several middle-income economies are followers

Several middle income economies are followers, mainly users of ADP technologies. These economies aspire to foster innovation-driven development, away

> **Strategies for smart manufacturing could benefit from clearer pathways towards explicit desired outcomes**

from commodities and traditional industrial products and increasingly moving into higher value added sectors. Several, such as Brazil and India, host smart manufacturing–ready firms (Chapter 3) and are even competing in economic activities traditionally reserved for highly industrialized economies (Daudt and Willcox 2016, IfM-UNIDO 2017). But most lower- and middle-income countries are either latecomers or lagging behind in their strategic positioning towards ADP technologies.

Country strategies could benefit from better articulation of the milestones, resources and pathways

As discussed here, country strategies for smart manufacturing could benefit from better articulation of the milestones, resources and pathways towards explicit desired outcomes. Otherwise, latecomers and laggards will still struggle with developing national policies around information and communications technologies (ICT) to improve framework conditions for digitalization and related infrastructure.

…and blend different policy realms

Strategies towards ADP technologies take diverse forms

Strategies towards ADP technologies applied to manufacturing, found throughout the world, take diverse forms: industrial policies or science, technology and innovation plans, digitalization strategies or national digital agendas, and standalone documents bearing terms such as Industry 4.0, advanced manufacturing, smart manufacturing or specific ADP technologies. Alternatively, countries expand and leverage already existing industrial development plans or innovation strategies. Colombia, for example, included Industry 4.0 in preparing the National Development Plan, as part of a national pact for a digital society and the 4IR (Colombia, DNP 2018).

Among developing country strategies, the most advanced and ambitious is Made in China 2025

Among developing country strategies, by far the most advanced and ambitious is Made in China 2025, which the Chinese government adopted in 2015 (State Council of the People's Republic of China 2015). Made in China 2025 is a comprehensive initiative to upgrade China's manufacturing industry from a manufacturing giant into a world manufacturing power. The strategy seeks to close the gaps with developed countries in innovation, efficiency in resource use, industrial structure, digitalization and product quality.

The next tier of countries includes followers in production and use

The next tier of countries includes followers in production such as Brazil, which adopted the Science and Technology and Innovation Plan for Advanced Manufacturing (Brazil, MCTIC 2017). The tier also includes followers in use. In Thailand, for instance, the basic elements of the national strategy, Thailand 4.0, are in the 20-Year National Strategy 2017–2036 and the 12th National Economic and Social Development Plan 2017–2021 (Baxter 2017; Thailand, Government Public Relations Department 2016). In South Africa, the Industrial Policy Action Plan (IPAP) 2017/18–2019/20 features a chapter on enhancing the country's readiness for Industry 4.0 (South Africa, DTI 2017), while the latest White Paper for Science, Technology and Innovation proposes a strategy to leverage science, technology and innovation to assist South Africa tackle the 4IR (South Africa, DST 2018). Similarly, Malaysia's National Policy on Industry 4.0 (Industry4wrd) seeks to boost the country's industrial performance and endorses efforts to achieve the SDGs (Malaysia, MITI 2018). Chile, despite being a latecomer to ADP technologies, is one of the first to adopt a strategy for it. The Strategic Programme Smart Industries (PEII) 2015–2025, announced in 2016, introduces a vertical approach looking into problems, needs and possible solutions for individual industrial sectors (Chile, CORFO 2016).

Other countries have a roadmap or general guidelines

Other countries have a roadmap or general guidelines for developing national strategies either in place or nearing completion. Mexico adopted in 2016 a

> **Participatory approaches are recommended for strategy development**

roadmap towards the adoption of Industry 4.0 strategies and technologies to increase domestic value addition in manufacturing (Mexico, Ministry of Economy 2016). Kazakhstan, in the new development strategy Kazakhstan 2050, expects the technological revolution to help meet the country's aspiration of achieving economic performance at a level similar to the world's top 30 countries (Nazarbayev 2018).

India, an advanced follower, is leveraging efforts already in place

Through the Make in India initiative, the government seeks to combine industry and Internet of Things (IoT) technologies, and its Smart Cities Mission should help build 100 smart cities across the country (Make in India 2017). Through the Digital India programme, the government intends to promote manufacturing and the use of ICT infrastructure (Roland Berger GMBH 2016).

The model is to bind manufacturing to broader national development aspirations and plans

Whatever the form of national response, the ideal situation is for country strategies surrounding smart manufacturing to bind manufacturing to broader national development aspirations and plans. Whether an industrial development plan or a science, technology and innovation development plan, what matters for such a document is to focus the collective aspirations and commitment around the future of manufacturing and its contribution to national development.

Basic elements of strategy design and development

Build on multistakeholder, participatory processes

They help to gather different perspectives and build common understandings…

Through multistakeholder, participatory processes, policy-makers can foster shared visions of strategic goals, identify tested policy tools for scaling up, inform the design of policy incentives or uncover gaps between different types of firms (Rodrik 2018). Several developing countries still lack a formal strategy and are engaged in consultations and other participatory policy-making processes with a view to developing roadmaps or national strategies through the work of special task forces or working or consultative groups (Santiago 2018). In Turkey, for instance, under the overall leadership of the Higher Council of Science and Technology (BTYK), the Scientific and Technological Research Council (TÜBİTAK) coordinated the Smart Manufacturing Systems Technology Roadmap, which builds on digitalization and interaction within the scope of ADP technologies and factories of the future. Through a comprehensive participatory process, including firm-based surveys, it was possible to define three technology groups—digitalization, connectivity and future factories—with 10 technology-based strategic targets and 29 critical products, research and development (R&D) projects and priority sectoral applications (Tansan et al. 2016; Turkey, TÜBİTAK 2019). Similar consultative processes to inform the development of national strategies can be identified in Argentina, Brazil, China and other emerging industrial economies (Santiago 2018, State Council of the People's Republic of China 2015).

…and to mobilize knowledge and experiences from multiple stakeholders

Participatory approaches are recommended for strategy development because collaboration among multiple agents can detect emerging changes even at an early stage (Planes-Satorra and Paunov 2019). When combined with policy tools such as strategic foresight and market intelligence services, participatory processes can help policy-makers anticipate opportunities, threats or vulnerabilities early on (UNIDO 2017c). Given the rapid pace of ADP technologies, collaborative multistakeholder approaches can identify where supporting capacity development is needed and help domestic firms identify or anticipate changes in demand and in the structure and dynamics of value chains. Participatory approaches in follower and even latecomer countries are consistent with the experience

“ADP technologies require a comprehensive government response with central coordination from the highest levels

of several frontrunner economies where the preferred approach remains to use working groups, stakeholder consultations and calls for proposal (Digital Transformation Monitor 2017).

In Brazil, consultations were based on a triple-helix approach

In Brazil, the development of the Science and Technology and Innovation Plan for Advanced Manufacturing involved the Ministry of Science, Technology, Innovation and Communications (MCTIC), and the Ministry of Industry, International Trade and Services (MDIC) (Brazil, MCTIC 2017; Portal Brasil 2017). Consultations were based on a triple-helix approach to the promotion of productive and scientific and technological activities with participation of government, private entities and education and research organizations. Significant knowledge came from a task force consulting private organizations on their perspectives around the challenges and opportunities stemming from smart manufacturing across different Brazilian industries and regions (Brazil, MDIC-MCTIC 2016). And the National Confederation of Industry (IEL 2018) documented issues of supply and demand expected to influence the adoption of smart manufacturing in the country.

Chile built on previous learning to foster digitalization

Similarly, elaboration of PEII 2015–2025 in Chile built on previous learning from initiatives to foster digitalization in the construction sector through the Building Information Modelling initiative—part of the Strategic Programme for Sustainable Construction (Programa Estratégico de Construcción Sustentable—PECS), which included a task force to identify challenges and opportunities associated with the sector’s digital modernization.

Collective thinking underpins the elaboration of roadmaps or national strategies

Collective thinking underpinning the elaboration of roadmaps or national strategies often informs proposals for additional diagnostic studies targeting strategic sectors or individual technologies, while governments aim to leverage ongoing initiatives and pilot projects. Expected outputs from these exercises include sectoral or technological white papers and proposals for creating clusters of firms specialized in a particular technology or set of technologies linked to the future of manufacturing.

The planning of strategic responses can also build on independent diagnostic studies carried out or sponsored by the private sector. In Turkey, in-depth studies cover automobiles, white goods, textiles, chemicals, machinery and food and beverages (Tansan et al. 2016). And for India’s automotive sector, a private entity has conducted specialized studies on the readiness for smart manufacturing (Grant Thornton 2017).

Address complexity through a comprehensive government approach

Smart manufacturing requires comprehensive responses with central coordination

The comprehensiveness and across-the-board nature of ADP technologies require a comprehensive government response with central coordination from the highest levels of government (Lee et al. 2019). Such high-level involvement is particularly evident in Asian economies with a strong tradition of active industrial policies. But it is not negligible in other contexts where industrial policy has been a difficult topic.

Leadership in developing and implementing national strategies is generally shared

The experience of follower countries confirms that leadership in developing and implementing national strategies is generally shared between ministries of industry and ministries for science, technology and innovation (Santiago 2018). In South Africa, the Department of Telecommunications and Postal Services (DTPS), the Department of Science and Technology (DST) and the Department of Trade and Industry (DTI) were selected by government to lead and develop an integrated strategy and policy in consultation with industry, labour and civil society

> **To drive ADP technologies, the private sector can become a strategic industrial development partner**

(Kraemer-Mbula 2019). Collaboration between DTI and DST facilitated the development of policy and technological scenarios for the future of manufacturing, and the corresponding responses required by the country (South Africa, DTI 2017). To coordinate work across government, South Africa established a Presidential Commission on the Fourth Industrial Revolution in 2019, with 30 members from different sectors of society and chaired by the country's president (Kraemer-Mbula 2019). The commission will identify relevant policies, strategies and action plans to position South Africa as a competitive global player in smart manufacturing (South Africa, The Presidency 2019). Similar forms of organization and coordination of actions for the 4IR are expected in Colombia, for example (Colombia, DNP 2018).

An additional tier reflects sectoral perspectives

An additional tier of relevant government entities introduces perspectives to national strategies from the higher education, health, mining, labour and ICT sectors. In 2017, Viet Nam issued a special directive allocating roles and responsibilities to different agents with a view to fast-forwarding the adoption of ADP technologies in manufacturing in the period up to 2045 (Nguyễn Xuân Phúc 2017; Viet Nam, Central Economic Commission 2018). Government and collaborating representatives consider manufacturing, education and science and technology institutions as the core drivers of digitalization and eventually smart manufacturing in the country (Viet Nam, Central Economic Commission 2018). In Latin America, Chile's PEII 2015–2025 has made explicit the government entities, programmes and initiatives with potential and interest to build synergies (Chile, CORFO 2016).

Foster strategic partnerships with domestic and external agents…

The private sector provides more than investment

To drive ADP technologies and smart manufacturing in most countries, the private sector can become a strategic industrial development partner, beyond providing financial resources and creating new business ventures. Through innovation, the search for new business models, initiatives to raise awareness or sponsoring or directly conducting sectoral diagnostics, the private sector informs policy-making and policy implementation for building industrial development capabilities (Santiago 2018, Santiago and Horst 2018).

Direct and active private sector involvement is essential

Fostering direct and active private sector involvement is essential for countries at the early stages of developing strategy. This encouragement bolsters consultative groups and other governance mechanisms responsible for the design, monitoring and coordination of working groups or other implementation mechanisms. Chile and Mexico have structured private sector participation in planning. In Chile, CORFO (Corporación de Fomento de la Producción), the national economic development agency, is responsible for implementing the PEII 2015–2025. But a Directive Council comprising representatives from public and private sector organizations will oversee implementation (Chile, CORFO 2016). Mexico's roadmap was drafted through a collaboration between the Ministry of Economy, ProSoft 3.0 (an official programme for the promotion of the domestic software industry), the Mexican Association of Information Technologies and other private sector organizations.

Private sector associations raise awareness

Private sector associations raise awareness through public events, conferences, workshops and by sponsoring or conducting sectoral diagnostics. The Confederation for Indian Industry prepared India's Readiness for Industry 4.0, with a focus on domestic automotive sector (Grant Thornton 2017). Similarly, in Colombia, collaboration between the Chamber of Industry and the Ministry of Information and Communication Technologies led to the establishment of an Observatory for the Digital Economy, which conducted the first survey of the digitalization of the Colombian economy in 2017 (Colombia, MinTIC-CCB 2018).

Innovation with ADP technologies seems to require new forms of public policy and public–private partnerships

4

Accelerating learning curves by leveraging international collaboration

Foreign partners in planning include multinational ICT firms and consulting firms. Collaboration with these foreign organizations can help countries leapfrog by leveraging know-how and experience. Partnerships with large multinational ICT firms or consulting firms help in carrying out studies on the state of specific smart manufacturing technologies—or in piloting novel business models and initiatives. The partnership between Microsoft and Fundación Chile supported a study on the state of cloud computing in the country (Fundación Chile and Microsoft 2016). The findings indicated that penetration of these technologies among Chilean firms remained low, with barriers to adoption from high upfront investment costs or tariff rates, and from low awareness and understanding of senior private sector executives of the risks associated with the novel technologies.

Followers and latecomers are pursuing collaboration with frontrunners

Follower and latecomer countries are pursuing collaboration with organizations from frontrunner economies, and the potential to expand this strategy looks significant. German organizations are frequent partners of choice in developing countries (Santiago 2018). Partnerships frequently involve the German and the host country's chambers of commerce, specialized research institutes or large multinational firms with recognized leadership in advanced technologies and related services—such as Siemens, the Fraunhofer Institute, and acatech (the German Academy of Science and Engineering). Activities include mapping the digitalization of domestic industries and identifying promising sectors (Box 4.2), setting up technology transfer offices to help the host country become a regional provider of ADP technologies and related services (Malaysia, Mexico) and broad collaboration on science, technology and innovation (Brazil). Several other activities foster technology transfer, human resource development, joint implementation of pilot projects and targeted SME support for automation and data management tools and business models (Argentina, Egypt, Thailand) (Santiago 2018). The Sino-German collaboration on manufacturing shows how countries at different stages of development can support development of their respective national strategies (Box 4.3).

Box 4.2
Cooperation for a new digitalization strategy for Kazakhstan

Kazakhstan's new digitalization strategy, Digital Kazakhstan, benefited from the collaboration of Germany's Fraunhofer Institute with the Kazakhstan Ministry of Industry and Infrastructure Development (MIID). Activities included a diagnostic study on the readiness of about 600 domestic companies to adopt smart manufacturing. Mining firms appeared to be better prepared technologically because of their higher exposure to international competition (Kazakhstan, MIID 2018). Enterprises in textiles, food and other sectors are piloting model digital factories and, on the basis of results, plan to popularize digital technologies, demonstrate the effects of digitalization, identify barriers to digitalization and develop advanced support tools (Kazakhstan, MIID 2018).

A technological audit, using the Fraunhofer Institute's methodology, plans for local companies to digitalize production processes, business models, equipment maintenance, supply chains, customer interactions, training and other relevant areas. Enterprises with semi-automated production are to progressively transform into digital factories, thus optimizing production processes. Pilot companies started implementing these activities in October 2018.

Source: UNIDO elaboration

...but be ready to address trade-offs

Distributed leadership requires enhanced ownership and coordination

Innovation with ADP technologies seems to require new forms of public policy and public–private partnerships (Lee 2019). Single ministries may not have all the resources needed to address challenges and capture opportunities. Shared leadership requires enhanced coordination across government organizations and

> **Indicators can help monitor and evaluate progress promoting and adopting ADP technologies, but there is no single way to do so**

Box 4.3
Sino-German cooperation for smart manufacturing

In 2015, China and Germany agreed to jointly promote the readiness of their respective economies for smart manufacturing by linking Made in China 2025 and Industrie 4.0 through a memorandum of understanding signed by the China Ministry of Industry and Information Technology (MIIT) and the German Ministry of Economy and Energy. Standing out among the proposed activities is the promotion of networks between Chinese and German enterprises in smart manufacturing.

Collaboration is already bearing fruit through a jointly established Sino-German Industrial Park as a platform to connect Chinese enterprises and German technology.

In 2016, MIIT selected pilot demonstration projects in accord with the Sino-German smart manufacturing cooperation arrangement, with Chinese firms applying according to their own development strategy. Sino-German experts evaluated projects and confirmed the first batch of 14 pilot demonstration projects, for example, the Industry 4.0 exploration for the iron and steel industry between China Baowu Steel Group Corporation and Siemens. In 2016 Baowu Steel and Siemens signed a strategic agreement, Joint Exploration Program of Industry 4.0, with the endorsements of both governments (Baosteel Co., Ltd. 2016).

Source: UNIDO elaboration

between government and private and academic organizations. Consultation and timely collective responses are needed from multiple ministries, with buy-in and coordination from the highest level of government.

Fostering formal mechanisms and platforms modelled on the Industry 4.0 platforms

Several follower countries are fostering formal mechanisms and platforms modelled on the Industry 4.0 platforms found in different developed, mostly European, countries (European Commission 2019, Planes-Satorra and Paunov 2019). An example is South Africa's high-level national collaborative platform proposed in the draft white paper on science, technology and innovation (South Africa, DST 2018). The platform advises how to respond to the opportunities and risks in smart manufacturing, including identifying and supporting priority science, technology and innovation programmes.

Viet Nam is developing a national response with the Prime Minister's direct involvement

Viet Nam is developing a national response for smart manufacturing with the Prime Minister's direct involvement in diverse awareness-raising activities and consultations with international experts. The approach includes summits and international gatherings to raise awareness, explore and possibly tighten public–private collaboration, and showcase technologies and solutions available to domestic agents interested in smart manufacturing. A first meeting in 2016 conveyed a basic understanding of ADP technologies, the second meeting looked at adoption in agriculture, industry and services and the third, in 2018, was more explicit on how to implement the 4IR in the country.[2]

Similar top-down approaches can be found in Chile

Similar top-down approaches can be found in Chile, where a recently created Bureau for the Economy of the Future, under the Ministry of Economy, Development and Tourism, is directed to insert the country in the 4IR through the analysis, coordination and definition of pertinent public policies. The bureau is also coordinating strategic projects to leverage existing scientific and technological infrastructure and other related activities in the country (Chile, Ministry of Foreign Affairs 2019).

Broad indicators can help monitor and evaluate progress

Broad indicators can help monitor and evaluate progress promoting and adopting ADP technologies, but there is no single way to do so. Aggregate data useful for monitoring industrialization in general may miss the full complexity of smart manufacturing. Generally, monitoring and evaluation can be improved through more concrete benchmarks, indicators, baselines and criteria for success or failure

> **“Challenges imply choices about specialization in smart manufacturing—in either the use or the production of novel technologies**

(Liao et al. 2018, Santiago 2018). Followers such as India and Malaysia have defined broad macro-level indicators linked to overall industrialization strategies, foreign direct investment (FDI) flows, productivity growth, innovation capacities or high-skilled employment (Santiago 2018). For example, India's National Policy for Advanced Manufacturing expects to assist in increasing the share of manufacturing in gross domestic product (GDP) from 16 percent in 2016 to 25 percent in 2025 (Grant Thornton 2017). The difficulty is in the linking promotion of smart manufacturing to performance at such an aggregate level.

The size of specific markets can be benchmarks

The size of specific markets can be benchmarks, as can competitiveness indices. Several countries propose assessing the expected value of domestic markets for specific technologies and applications and to derive more granular performance indicators, which are often but not always consistent with specific programmes or interventions. For instance, the government of Mexico has targeted its market for IoT services at about $8 billion by 2022 (Mexico, Ministry of Economy 2016) but provides no information on how to get there. Also common as benchmarks are international indexes on competitiveness and related performance indicators. Kazakhstan seeks to emulate the economic performance of the top 30 countries by 2050 (Kazakhstan 2019), while Malaysia targets strengthening its innovation capacity and capability to climb from 35th to the top 30 in the World Intellectual Property Organization's Global Innovation Index by 2025 (Malaysia, MITI 2018).

Investments and innovation performance as benchmarks

Also identified are intentions to evaluate investments leveraged through national smart manufacturing strategies, or improvements in innovation performance. Chile's PEII 2015–2015 includes intermediate targets for 2015–2017 (short term), 2018–2020 (medium term) and 2020–2025 (long term), coupled with estimates of the investments required for each period and their possible sources (Chile, CORFO 2016). Emphasis seems to be on creating framework conditions through digitalization, identifying strategic sectors and working with the private sector in implementation. In China, by contrast, perhaps because of its more advanced situation in relation to the 4IR, Made in China 2025 focuses more on industrial and innovation performance, including indicators on R&D inputs (expenditure intensity) and outputs (patents per revenue), labour productivity, penetration of ICT infrastructure or ICT applications and contributions to environmental sustainability through CO_2 emissions, water consumption and solid waste rates (State Council of the People's Republic of China 2015). The performance targets specify improvements by 2020 and 2025 relative to a 2015 baseline.

Fostering capabilities to adopt ADP technologies

Address at least one and preferably more than one of four challenges

A country's ability to capture value from ADP technologies is contingent on addressing at least one and preferably more than one of four challenges:

- Adopting smart manufacturing systems to capitalize on efficiency gains, flexibility, speed/responsiveness, precision and customization.
- Becoming a manufacturer and supplier of key ADP technologies.
- Positioning the country as a provider of specialized ADP services.
- Building key enabling infrastructures to underpin the expansion of smart manufacturing (IfM-UNIDO 2017).

These challenges imply choices about an economic agent's specialization in smart manufacturing—in either the use or the production of novel technologies. The choice implies different stages of capability accumulation across sectors, technologies or applications. But determining the extent of expected success is complex and uncertain (Steinmueller 2001).

> **Digitalization and access to broadband internet are persistent constraints for smart manufacturing**

Enhance readiness for smart manufacturing with interventions, dedicated programmes and incentives

Three main types of issues can be derived for strategic policies to enhance readiness for ADP technologies (IfM-UNIDO 2017):

- Developing framework conditions—including but not limited to infrastructure—at different levels. The range of possible interventions is broad, including regulatory reforms, facilitating convergence and synergies across policy realms, conducting studies on specific digital and nondigital activities or individual technologies in the smart manufacturing suite, and creating digital parks, often linked to FDI promotion or facilitating connections with international initiatives for digitalization and smart manufacturing (Brazil, MCTIC 2017).
- Introducing dedicated programmes, facilities and incentives to raise awareness and stimulate the interest of domestic agents. Suggested initiatives involve partnerships between academic organizations, domestic and foreign firms and others, including novel R&D support schemes and technology transfers for smart manufacturing.
- Building capacity, particularly to enable adjustments in labour markets—from strengthening science, technology, engineering and mathematics (STEM) education at various levels, to developing specialized programmes with private sector collaboration, to enhancing vocational training and higher education programmes for smart manufacturing.

Focus on framework conditions

Digitalization is a prerequisite for firms and countries seeking smart manufacturing

Regardless of a country's industrialization, digitalization and access to broadband internet are persistent constraints for smart manufacturing (Banga and Willem te Velde 2018a; Colombia, DNP 2018; European Commission 2017a). For frontrunners such as the United States, improving digital adoption, particularly among SMEs, is recommended to boost productivity (McKinsey & Co 2017; see Box 4.1). The European Commission recognizes the need to close the gap between top digital players and lower-performing countries and to invest substantial resources to tap into emerging digital opportunities. It has pledged to mobilize some €50 billion in public and private investment to support the Digitizing European Industry strategy through 2020 (European Commission 2017).

Update regulations, open the ICT sector to investment and foster broadband infrastructure

Latecomer and follower countries also struggle to improve framework conditions for digitalization through national ICT policies or digitalization strategies that stress building digital capabilities (Box 4.4). Among recommended actions are updating regulations or deregulating and opening the ICT sector to investment (including to foreign investors) and fostering broadband infrastructure to enhance access to high-speed internet and develop big data applications,[3] IoT, visualizations and related technologies. These actions coincide with those identified as basic elements of any sound digital industrialization policy (Sing 2017).

Enhanced digitalization improves the business environment and broadens people's internet access

Enhanced digitalization is necessary to improve innovation performance and enrich the business environment (Chile, Ministry of Foreign Affairs 2019; Peru, MEF 2018), preparing economic agents to adopt ADP technologies while bridging inequalities in access to internet and related digital services among broader population segments (Peru, MTI 2019). Currently, several countries are aiming to update existing frameworks to allow industrial digitalization and foster smart manufacturing as a driver of industrialization (Box 4.5). But in many countries, firms' use of digitalization in day-to-day operations remains modest (Chapter 3).

Search for sectoral advantages to promote in national strategies

In many countries, policy-makers are looking for exemplary experiences to inform smart manufacturing policies. National strategies in follower countries tend

Strategies tend to be fairly open about the choice of either the technologies or the priority sectors to develop advanced applications

Box 4.4
Priorities for digitalization in Africa

African countries face serious risks of a growing digital divide and difficulties in benefitting from the rapid uptake of new digital technologies and falling labour costs (Banga and Willem te Velde 2018a). But they should expect to profit from a longer transition and adjustment than more advanced countries have had. Manufacturing remains a valid and feasible development path if countries continue to invest in industrial capabilities with a two-prong approach:

- Focus on upgrading capabilities in less-automated sectors—food and beverages, garments and paper—to capture windows of opportunity for increased local production and regional trade, moving progressively into higher value added activities.
- Enhance readiness for the more digital future through improved access to broadband and developing technical skills and technology hubs.

Policies should address frameworks for increased digitalization and investment, including better and more affordable access to internet and other information and communications technologies (ICT) and ICT infrastructure and participation in global value chains. Governments may turn to educational institutions and local and community centres to provide free or subsidized access to the internet.

Public funding should be expanded for ecosystem enablers such as technological and innovation hubs already present in the continent, and for manufacturing and service start-ups. And taxes and incentives should help in bridging rural–urban digital divides and increase access to digital technologies. Creating a regional register for digital-related trademarks, and promoting regional and continental e-commerce and trade in digital products and services, should foster innovation and build firm-level capabilities.

Public–private collaboration should contribute to investments in education and complementary skills through revising and reorienting the curriculum around science, technology, engineering and mathematics and providing better technical and vocational education and training.

Source: UNIDO elaboration based on Banga and Willem te Velde (2018b).

to be fairly open about the choice of either the technologies or the priority sectors to develop advanced applications for (Digital Transformation Monitor 2017, Santiago 2018), so manufacturing areas may not always be explicitly identified (Liao et al. 2018). Through a mix of comparative advantage–compliant and comparative advantage–defiant approaches, policy-makers are searching for windows of opportunity in a heterogeneous set of industries and technological applications. Agriculture and the aerospace industry feature prominently in national strategies, perhaps reflecting the dual economic structures of several developing countries. Digital technologies, automation and robotics suggest efforts in new sectors, while mining, electronics, automotive or chemicals suggest attempts to build on existing comparative advantages.

Follower economies target sectors where smart manufacturing already exists

Followers tend to target sectors where smart manufacturing already exists—aerospace, automobiles and pharmaceuticals—or where it has potential to enter in full force once the framework conditions are improved. Those sectors, or firms in those sectors, are examples to be emulated or scaled up (Malaysia, MITI 2018; Mexico, Ministry of Economy 2016).

A distinction between sunset and sunrise industries

Often, a distinction is made between sunset and sunrise industries, sometimes under different names. Building on the 11th Malaysia Plan, Malaysia, MITI (2018) distinguishes catalytic and high growth potential industries (electrical and electronics, machinery and equipment, chemicals, aerospace and medical devices) "as game changers for the manufacturing sector" from other more mature high growth sectors (automotive, textiles, transport and pharmaceuticals). Thailand has identified 10 strategic industries in two development strategies:

- Reforming existing industrial sectors (the "First S-Curve"): food, automotives, electronics, affluent tourism and medical tourism and agriculture and biotechnology.
- Scaling up future growth engines (the "New S-Curve"): digital industry, medical services, automation and robotics, aviation and logistics and biofuels and biochemical (Board of Investment

> **Both frontrunner and follower economies pursue smart manufacturing as part of regional development strategies**

Box 4.5
Digitalization as a prerequisite for smart manufacturing

Kazakhstan

Kazakhstan, through its Kazakhstan 2050 national strategy, seeks to foster technological upgrading of basic industries until 2025, including elements of advanced digital production technologies to enhance industrial competitiveness (Nazarbayev 2018). The Ministry of Industry and Infrastructure Development and the Ministry of Information and Communications are working on a draft programme of Digital Kazakhstan, an umbrella for digitalization initiatives, including measures targeting a transition to smart manufacturing. The draft programme considers attracting foreign partners for research and development (R&D), emphasizing manufacturing and mining. Similar efforts at enhancing digitalization in Central Asia can be found in Kyrgyzstan, including setting up new government organizations to design and implement digitalization strategies (Osmonova 2016).

Mauritius

Digital Mauritius 2030 Strategic Plan is the latest incarnation of the country's development plan for economic digitalization (Kraemer-Mbula 2019). Led by the Ministry of Technology, Communication and Innovation (MTCI), this policy framework builds on the successful implementation of the previous plans, Smart Mauritius and Vision 2030. The country's e-government projects have improved the efficiency of government-to-government, government-to-business and government-to-citizen transactions and reduced associated costs (Mauritius, MTCI 2018).

Vision 2030 is moulded around future technologies, with a view to boosting the country's readiness for the 4IR. It sets phases of digital transformation over the next decade and plans the continuous development of the information and communications technology (ICT) sector as the pillar of competitiveness and growth, which in 2018 contributed 5.6 percent of GDP, employed around 23,000 people, and saw ICT export growth of around 4.4 percent (Mauritius, MTCI 2018).

Digital Mauritius 2030 Strategic Plan focuses on developing an enabling environment for digital implementation. Specific areas of intervention include ICT governance, talent management and the national broadband strategy, Protection of Intellectual Rights, Data Protection and Data Privacy Issues and Cyber Security. The goal is to provide a stable and transparent ecosystem for economic growth in the 4IR (Mauritius, MTCI 2018).

Viet Nam

Over the past 15 years, Viet Nam has adopted several policies, master plans and a host of laws around information technologies, intellectual property rights, e-transactions, and cyber-security—to foster investment in infrastructure, adopt multimedia, and promote e-commerce and advanced technologies in production and business (Cameron et al. 2018). The result is a complex governance structure sustaining a sectoral system of innovation around the digital economy, which is expected to provide a solid basis for smart manufacturing (Cameron et al. 2018; Viet Nam, Central Economic Commission 2018).

Source: UNIDO elaboration.

2017; Thailand, Government Public Relations Department 2016).

South Africa, recognizing trends towards servicization, targets knowledge-intensive design and health services and manufacturing-related services. Priorities include such cross-cutting or generic technologies as biotechnology and such digital technologies as robotics, 3D printing and the IoT (South Africa, CSIR-DST 2016).

Capitalize on smart manufacturing as an emerging approach to regional development

Both frontrunner and follower economies pursue smart manufacturing as part of regional development strategies. In Europe, such strategies are frequently linked to smart specialization initiatives under the framework of the European Commission's current approach to innovation policy, which seeks to capture regional productive specialization, including ICT clusters and other strategic sectors (Digital Transformation Monitor 2017; Spain, Ministry of Industry, Trade and Tourism 2019). The Basque Country's smart manufacturing strategy, Basque Industry 4.0, builds on more than 30 years of experience promoting industrial development through clusters, and an extensive capability base for innovation and manufacturing production technologies. Digitalization constitutes a challenge for future development of local industry (Kamp et al. 2019). So

> **Through funding for innovation, digitalization and pilot initiatives, governments can steer resources towards the development of ADP technologies**

Basque Industry 4.0 includes pilot activities to assist domestic SMEs in training for the technologies associated with smart manufacturing and digitalization. The strategy also sponsors firms interested in conducting self-diagnosis and fine-tuning for smart manufacturing (Basque Industry 4.0 2017).

Mexico and Viet Nam support regional initiatives that match national targets

Among follower economies, Mexico and Viet Nam have recognized and explicitly pledged support to regional initiatives with different degrees of alignment with central government initiatives and national development targets (Box 4.6). Regional or provincial government strategies may supplement the comprehensive government approach discussed earlier.

Fostering smart manufacturing readiness to promote ADP technologies

Is there a case for mission-oriented interventions?

Through dedicated funding for innovation, digitalization and pilot initiatives on specific technologies, applications or business ventures, governments can steer resources, capabilities and incentives towards the development of ADP technologies. South Africa's Industrial Policy Action Plan 2017/18–2019/20 proposes a Sovereign Innovation Fund to provide funding certainty for high-technology projects, particularly in smart manufacturing-related areas (South Africa, DTI 2016). The government pledged a seed investment of 1–1.5 billion rand (about $111 million) in 2019/2020 for the adoption of locally developed technologies (Santiago 2018). The fund is part of a strategy to help domestic firms benefit from technology transfer, diffusion and acquisition, including through global original equipment manufacturers in key value chains.

China's Zhejiang province promotes the adoption of cloud technologies

An exemplary initiative to promote adoption of ADP technologies was launched in China's Zhejiang province. It combines funding with a complex approach to foster supply-push and demand-pull interventions and an ambitious capacity-building programme around cloud computing technologies and applications. The emerging evidence suggests that the programme is contributing to a rapid uptake of cloud computing technologies and their commercial applications (Box 4.7).

Box 4.6
Nuevo León 4.0: A regional initiative around smart manufacturing in Mexico

In May 2017, the provincial government of Nuevo León, Mexico, announced Nuevo León 4.0, which aims to support the modernization of production systems and the introduction of new models for business and smart manufacturing (Mexico, Gobierno Nuevo León 2017). The strategy—a five-helix collaboration of academia, industry, government, entrepreneurs and investors—will promote digital transformation of the local ecosystem. In addition to contributing to the strategy's governance mechanisms, these stakeholders will be organized in distinct action groups around such areas as ethics, public policy, technological infrastructure, and communication architecture. The goal is to make the province a benchmark smart economy in the Americas on a course towards 2025 (NL4.0 2019). A two-year memorandum of understanding was signed with Basque Industry 4.0 in 2018 to govern cooperation between two of the most industrialized regions in their respective countries.

Ongoing initiatives under the Nuevo León 4.0 include:

- Developing research and development infrastructure for specific technologies—for example machine-to-machine communication and machine learning.
- Collaborating with Mexico's federal science and technology and innovation authorities to leverage dedicated funding.
- Launching special awards to recognize manufacturing and service firms already developing and implementing smart solutions.
- Redesigning engineering programmes and launching education programmes to meet the technological and industrial requirements of smart manufacturing (NL4.0 2019).

Source: UNIDO elaboration.

> Policy interventions need to align with the requirements of firms with distinct degrees of readiness and openness to ADP technologies

Box 4.7
Fostering the development and adoption of cloud computing in Zhejiang province

In April 2017, the local government of the Zhejiang province launched an action plan, Enterprises Deploying the Cloud, to raise the awareness of manufacturing companies about cloud technology and its applications. The initial target was to assist 100,000 firms to adopt cloud technology over 2018–2020.

Governance: A coordinated mechanism, including provincial, city and county governments, organizes and mobilizes public awareness activities. Each city in the province has plans to identify and allocate concrete tasks to villages and towns. Local governments have developed a cloud strategy for distinct industries and firms.

Capacity building: In 2017, local governments organized more than 1,100 seminars for cloud training, covering more than 90,000 firms and 100,000 participants. Each industrial firm, regardless of size or type, can attend seminars intended to enhance its willingness and practical ability to use cloud technologies. For small and medium-sized enterprises (SMEs), the first step is to secure basic cloud computing applications, but the complexity of the applications increases with the size and technological upgrading of firms. The provincial government has pooled funds to support promotion and training in cloud technology. It regularly organizes case studies to help companies learn from good practices.

Supply-driven interventions: Priority applications include upgrading management, R&D and innovation, reducing costs and increasing revenue. Content is classified in distinct categories—agriculture, manufacturing and services—and for items such as database, storage, network security, IT development and office training. The provincial government works closely with cloud service providers, system integrators and third-party organizations to establish an information communication platform for enterprises.
Firms can mobilize cloud applications according to their development requirements. In parallel, the city government established a cloud service platform to coordinate cloud service providers, cloud technology design developers, software and hardware developers, system integrators and industry associations to assess an enterprise's application and formulate plans for detailed cloud transformation projects. To meet firms' needs, the province has incubated 12 industrial cloud application platforms in textiles, commerce, finance and intelligent customer service.

Demand-driven interventions: The Zhejiang government has introduced diverse financial support methods to facilitate adoption of new technologies or foster innovation, particularly among SMEs. Voucher schemes lower the cost of cloud technology, and firms can redeem those vouchers with cloud platform service providers. On the basis of technical evaluation, the government selects certain firms to benefit from subsidies for significant pilot or demonstration projects.

Results: In about a year of operation, up to the third quarter of 2018, more than 218,000 firms in Zhejiang deployed the cloud, bringing the total number of adopters in the province to around 268,000.

Source: UNIDO elaboration.

Automation and digitalization are foundational technologies

Automation and digitalization constitute foundational technologies to enhance readiness for smart manufacturing. In Kazakhstan, the Ministry of Education and Science has an Industrial Automation Institute based in the Kazakh National Research Technical University. In collaboration with domestic universities and research institutes, the institute will carry out applied research and technology transfer, addressing the technological problems faced by business seeking to adopt smart manufacturing (Liter.KZ 2018).

Cater to different types of firms

Policy interventions need to align with the requirements of firms with distinct degrees of readiness and openness to ADP technologies. Globalized, highly competitive and productive sectors, often comprising large firms ready to adopt these technologies, coexist with a huge segment of firms, mainly domestic SMEs using outdated production models, with limited incentives to undertake innovation and technological upgrading. Firms that operate in traditionally nondigital markets differ from those with completely digital business models, particularly services on digital platforms (Colombia, DNP 2018). This brings to

> **Of particular concern is identifying the readiness, opportunities and bottlenecks for SME participation in the new technologies**

mind debates around the capabilities required to successfully move a firm from manufacturing to services (Sousa and Silveira 2017).

Public research infrastructure should showcase practical applications

In India, policy-makers intend public research infrastructure to contribute to Make in India by showcasing practical applications of ADP technologies, in order to raise awareness and demystify the concept through capacity building tailored to the needs of firms (Box 4.8). Centres are located to match local manufacturing specialization and the competences of firms.

Develop diagnostics, toolkits and tailor-made blueprints to assess readiness

Diagnostics, toolkits and tailor-made blueprints have to be developed to assess readiness for ADP technologies and to produce industry or country profiles showcasing the potential benefits of such technologies (Deloitte 2016, PwC 2016, World Economic Forum 2017). Of particular concern is identifying the readiness, opportunities and bottlenecks for SME participation in the new technologies, for example, through the Industry4WRD Readiness Assessment managed by Malaysia's Productivity Corporation platform (Box 4.9).

Frontrunner and follower economies foster collaboration and the cross-fertilization of ideas

To link firms of different sizes and technological capabilities, both frontrunner and follower economies foster collaboration and the cross-fertilization of ideas. In Mexico, MIND4.0 Monterrey 2019, recently launched as part of Nuevo León 4.0 (NL4.0 2019), is a start-up accelerator that emulates a similar pilot initiative in the Basque Country, BIND 4.0. It matches local manufacturing firms with domestic and foreign innovators and entrepreneurs—for the former to access solutions and talent and the latter to participate in mentoring and other business development support.

BIND 4.0 supports start-up development and growth in the Basque ecosystem

The BIND 4.0 programme, introduced in 2016 in the Basque Country, is the first international public–private initiative to function as start-up accelerator specialized in Industry 4.0 solutions to support start-up development and growth in the Basque ecosystem (Basque Industry 4.0 2017, SPRI 2019). It mobilizes local Basque Country firms—in healthcare, energy, agro-food and manufacturing —to function as catalysts by establishing contact with innovative entrepreneurs, either domestic or foreign. The entrepreneurs can expect to contract out with a catalyst company for

Box 4.8

Fostering SME participation in smart manufacturing: The C4i4 Lab in Pune, India

With the aim of supporting the implementation of Make in India, in 2017 four new centres for Industry 4.0 opened in Bangalore, New Delhi and Pune. While independent, they fall under the purview of SAMARTH Udyog (Smart & Advanced Manufacturing & Rapid Transformation Hub) program by Ministry of Heavy Industries & Public Enterprises, the Department of Heavy Industry. Their general mission is to enhance manufacturing competitiveness through a better understanding and broader adoption of Industry 4.0 technologies, particularly among manufacturing SMEs. A triple-helix approach—academia, industry and government—guides their operation.

The C4i4 Lab in Pune received a public grant of $2 million and raised an additional $700,000 in private funding. It focuses on supporting local SMEs, starting with diagnostic studies to determine their main challenges around smart manufacturing. With low awareness a main barrier, the lab supports workshops and demonstrations of smart manufacturing applications—and pilots for adopting SME-tailored solutions. Partnerships with local providers make it easier to consolidate demands from multiple SMEs, thus reducing the cost for solution providers.

An interview with the director of C4i4 Lab suggests that drivers of success include nurturing close relationships with the Industry Associations, fostering interaction with higher education institutions both for training and skill development and involving college graduates in diverse activities.

Source: UNIDO elaboration.

“Few strategies address smart manufacturing employment

> **Box 4.9**
> **Malaysia’s Industry4WRD Readiness Assessments**
>
> The Industry4WRD Readiness Assessment under the Industry4WRD initiative determines SMEs’ readiness and identifies gaps and areas to improve their prospects for adopting smart manufacturing technologies. It will focus on three “shifting factors”—people, process and technology—to identify gaps and raise the technological capabilities of 500 SMEs from 2019 to 2021 (allocating 210 million ringgit).
>
> The assessment uses a predetermined set of indicators to understand present capabilities and gaps, and to enable firms to prepare feasible strategies and plans towards Industry 4.0. It should help firms to:
>
> - Determine their state of readiness to adopt smart manufacturing technologies.
> - Identify the gaps and areas of improvement for smart manufacturing adoption and opportunities for productivity improvements and growth.
> - Develop feasible strategies and plans to implement projects incorporating new technology.
>
> A novel feature of the assessment is a module tailored for manufacturing-related services.
>
> A first call received around 300 applications for firms by March 2019, and the government aims to conduct more intensive awareness activities, especially in smaller cities.
>
> *Source:* UNIDO elaboration.

up to €150,000. Basque firms, in turn, can enhance their internationalization strategies and access talent, suppliers and solutions to specific challenges. In 2018 alone, the programme received 524 applications from firms in 64 countries, as local catalyst firms totalled 40, up from 15 in 2016.

Invest heavily in human resource and research capabilities

Capacity gaps exist between generations and between women and men

Chapter 2 in this report argued that the implications for employment that can be associated with adopting ADP technologies are subject to debate. The skills needed for the future will change, and this may bring adverse consequences for certain groups. Low-skilled workers, and women in particular, would more likely be hurt by automation and digitalization. A generation gap may also occur and widen since youngsters, more exposed and open to new technologies, may have an advantage.

Technology is not the only factor influencing employment

Technology is far from being the only factor influencing employment. Long-term structural changes in demography, labour relations and policy dynamics, as well as a redistribution of manufacturing activities and value chains, will also determine future global employment dynamics (Lee et al. 2019).

Limited technological experience creates ongoing problems in demands for skills

In building capabilities, limited technological experience challenges human capital development initiatives. Demands for employment and skills show the cumulative nature of manufacturing expertise and capabilities and the disadvantages of inadequate investment in human capital (Kraemer-Mbula 2019). Policy-makers should learn from pilot initiatives elsewhere, including those offering opportunities to enhance international collaboration and knowledge sharing.

Few strategies address smart manufacturing employment

Notwithstanding concerns about employment, few strategies address smart manufacturing employment. Attention seldom goes beyond problem statements. South Africa’s IPAP 2017/18–2019/20 is among the few national strategies to explicitly consider priority sectors that can help offset negative impacts on manufacturing employment (South Africa, DTI 2016). But specific actions to identify and promote such sectors are still unclear—and will be a task for the high-level national collaborative platform (South Africa, DST 2018).

So, explore the potential of technical and vocational education and training

The skilling, reskilling and upskilling for ADP technology requires new approaches to technical

> The DIY movements can assist governments in targeting small players, helping them acquire capabilities and generate employment

and vocational education and training. The Basque Country is experimenting with new approaches to training, upskilling and career reorientation according to emerging requirements of firms and the allocation of roles and responsibilities among agents with a stake in Basque Industry 4.0. Cluster organizations lead in implementing human resource development strategies, building on existing training models with upgraded teaching facilities and learning environments and testing new delivery methods. For instance, the Association of Electronic and Information Technologies (GAIA) runs pilot programmes, some in collaboration with the Department of Employment, Social Inclusion and Equality of the Provincial Council of Bizkaia, to undertake professional retraining in ICT fields with high demand for employment, targeting youth (GAIA 2019).

Incorporating new professionals in ICT

The GORAKA Training and Employment Plan for the Incorporation of New Professionals to the ICT sector supports companies, training centres and candidates (Kaltzada 2017). It uses gaming techniques to underpin selection and training, accompanied by support services for mobility, scholarships, knowledge management and digital labs.

A Basque Country–Colombia collaboration

GAIA recently entered an agreement to collaborate with universities in Valle del Cauca, Colombia, to foster digital culture and entrepreneurship among local students. It expects to nurture a win–win scenario, creating a digital cluster benefits Colombian localities while providing a richer ecosystem for Basque companies to reach out to partners and solution providers and, more importantly, to supplement the limited human resources available in the Basque Country.

Stimulate training and development to foster specific economic activities

In Malaysia, the Ministry of Human Resources offers a National Dual Training System equipping workers to use smart manufacturing technologies. Adopted in 2014 as a two-track vocational training scheme following the model of the German Dual Vocational Training Programme, this was the first of its kind in the suite of Malaysia's training programmes. The Penang state government is tapping into the programme to support skill development for the new Penang Automation Cluster launched in 2016, expected to become operational by the end of 2019. The cluster will support local electrical and electronics companies in becoming regional and global players, creating around 500 skilled jobs. The Penang State government has invested around 6 million ringgit.

Expose people to learning using new technologies

Direct experience and exposure and learning from the new technologies may be possible through the "do it yourself" (DIY) movements, which are spreading widely in several latecomer and follower countries (Box 4.10).

Do-it-yourself movements foster problem solving and peer-to-peer learning

The DIY movements can assist governments in targeting small players, helping them satisfy their needs, acquire capabilities and generate employment by raising awareness of new technology (Iizuka et al. 2019). They can also foster new forms of entrepreneurship and innovation and promote building capacity to use those technologies—including more general capacities gained through STEM education among youth. So far, however, industrial policy has mostly neglected DIY in addressing the challenges posed by smart manufacturing. So, the links between DIY and manufacturing remain slim, particularly for smart manufacturing. To generate greater impact, DIY would need to be embedded in larger ecosystems, including in education, as part of a broader industrial policy and for longer timespans. A few of the more progressive developing countries are already using DIY in that way, embedding DIY networks in initiatives around training and entrepreneurship, and using them effectively as a tool to foster innovation, including by consumers (Halbinger 2018).

> **“Follower economies are adopting research agendas to foster domestic capabilities to absorb ADP technologies**

Box 4.10
Creative spaces can advance and democratize manufacturing development

Various forms of creative spaces since the early 2000s, generically referred to as modern “do it yourself” (DIY) movements—such as fab labs, hackerspaces, makerspaces, tech/innovation hubs and creative spaces—are innovative attempts at bridging gaps left by markets and states in providing education, building capacity and furnishing smart manufacturing infrastructure.

Although different, DIY movements generally offer access to digital technologies that facilitate sharing knowledge and diffusing creative ideas among communities. They offer common spaces—physical or cyber —where individuals can collectively create or tinker with existing products to suit their needs with digital equipment and hard tools. The movements often offer possibilities for networking with possible investors, lenders, customers and business partners.

The movements’ core functions are education, learning, problem solving and fostering entrepreneurship, including peer-to-peer learning. They are commonly included among innovation policy tools to strengthen digital ecosystems around start-ups in advanced economies (Planes-Satorra and Paunov 2019). They can also foster university involvement, because many DYI facilities in developing countries are located within higher education organizations, which, in turn, provide equipment and trainers. The facilities train people in using digital equipment and tools to make prototypes as part of projects. Students gain experience with advanced digital equipment to increase their employability but also to venture into the market as entrepreneurs.

DIY movements usually search for solutions to development challenges at the individual or community level. But they could offer new avenues for general public engagement in manufacturing, opening spaces for inclusive and sustainable patterns of manufacturing development.

Source: UNIDO elaboration based on Iizuka et al. (2019).

Initiatives to facilitate exposure and training are already in place

Initiatives to facilitate exposure and training in foundational technologies such as automation are already in place. In Uruguay, the government established, in collaboration with UNIDO and the German industrial control and automation company Festo, the Centre for Industrial Automation and Mechatronics (CAIME) as a public technology centre to upgrade technical skills and encourage domestic firms to adopt smart manufacturing processes. CAIME shows that boosting technological capabilities in smart manufacturing is a gradual process that requires constantly matching a firm’s evolving needs (demand) and the country’s technical human resource pool (supply). The modular nature of CAIME’s laboratories and technologies allows for a cost-efficient adjustment of training modules and equipment based on changing technological trends and demands for specific skills.

Public research infrastructure enhances readiness

Follower economies are adopting research agendas to foster domestic capabilities to absorb, use and eventually develop ADP technologies. In Turkey, the Scientific and Technological Research Council (TÜBİTAK)’s 2016 and 2017 national call for research proposals focused on ADP technologies, including IoT (Erdil and Ertekin 2017). In Colombia, Colciencias—the Administrative Department for Science, Technology and Innovation —and the Tax Benefits Council amended the documents governing the types of projects that can receive support (Colombia, DNP 2018). Colciencias now gives higher scores to projects by companies in areas related to ADP technologies. And it is adding a new category for “the use, production, integration and appropriation of information and communications technologies, digital transformation and Industry 4.0” to be incorporated into science, technology and innovation programs and projects (Colombia, DNP 2018, p. 182).

Research agendas should capitalize on comparative advantages in specific fields

Novel research agendas also take advantage of comparative advantages in specific research fields. Chile

> **“Objective, evidence-based debates are needed to inform decision-making for designing and implementing national strategies for smart manufacturing**

expects to host about 70 percent of the world's radio astronomy capacities by 2020 (Chile, Ministry of Foreign Affairs 2019). The Office of Economy of the Future, in project Astrodata, will capitalize on the opportunity to process astronomical big data, not only for scientific applications and human capital development, but for economic purposes.

Follower countries are exploring ways to reorient research infrastructure

Follower countries are exploring ways to reorient existing research infrastructure, or create new facilities, particularly public or semipublic research centres specialized in ADP technologies. South Africa has proposed new research institutions linked to smart manufacturing and enhancing support and incubation for emerging industries (Kraemer-Mbula 2019). Saudi Arabia's National Industrial Strategy, now under development, is considering creating a network of public research centres to help firms improve productivity by adopting ADP technologies (Kingdom of Saudi Arabia 2018).

In sum

The arrival of ADP reinforces the pertinence of evidence-based strategies and policies

Evidence is needed to balance short-term concerns with longer-term development opportunities

This is not the first time the world has experienced uncertainty and anxiety due to rapid technological change (Mokyr et al. 2015). People tend to overemphasize short-term concerns about possible losses in employment, human welfare and the sustainability of technological change—and to underestimate the possible long-term consequences of change, such as the emergence of new industries and innovations leading to new, welfare-enhancing products and services. Thus, while policy initiatives are needed to cope with short-term adjustments in labour and other markets, policy-makers should also foster the building of capabilities to tap promising opportunities and to capture benefits stemming from long-term economic and social transformations. So, to inform decision-making for designing and implementing national strategies for smart manufacturing, objective, evidence-based debates are needed.

Endorse multistakeholder, participatory processes

Responses to smart manufacturing are best conceived as engaging multiple stakeholders, as documented in the literature (Santiago 2018). This is consistent with the principles of the new industrial policy, which stress multistakeholder participatory processes and public–private dialogues contributing to policy design and implementation (Rodrik 2007, 2018). This chapter, finding that several countries it reviews have participatory processes for preparing national smart manufacturing strategies, supports that approach.

But be mindful of the challenges implied by "multiple helix" approaches to policy making

Country responses often build around "multiple helix" approaches with academic, government, private sector and other organizations contributing to policy design and implementation. The organization and governance of such multistakeholder processes is complex and often challenges the possibility of ensuring that decisions follow an agreed roadmap, respect defined roles and responsibilities and are binding. Enhanced policy coordination mechanisms at multiple levels are needed to bring about expected commitments from multiple stakeholders during policy implementation. Gaps may become major constraints keeping developing countries from benefitting from the 4IR. Further research should review ongoing initiatives to organize, govern and sustain participatory processes and suggest new institutional frameworks and capabilities for policy-making, design and implementation to accomplish such strategies. The lessons that emerge may contribute greatly to policies addressing traditional disconnects and poor interactivity in innovation systems, particularly in follower and laggard countries.

> **The overarching pledge to leave no one behind in the 2030 Agenda for Sustainable Development calls for technological solutions to local problems accessible to all**

Responses to ADP reinforce the importance of capability building

Countries at distinct stages of development require different responses

Countries at distinct stages of development require different responses according to their accumulated capabilities, manufacturing experience and stance towards global manufacturing in general and smart manufacturing in particular. The future of manufacturing entails deep learning and unlearning, creating new capabilities and reorienting old ones and helping people unable to adapt to the new trends to move towards alternative income-generating activities. There is no easy short cut.

Capabilities influence readiness for identifying opportunities

The extent to which countries can turn the emergence of ADP technologies into opportunities to leapfrog or to avoid the risks of falling further behind will depend on individual country responses and readiness through active industrial policy, digital literacy, skills and education—and not just wage rates, domestic markets and positions in GVCs. Moreover, as the experience of different countries leading the adoption of ADP shows, there is scope to turn environmental concerns into an additional impulse for industrialization and growth.

...and are at the basis of catching up and forging ahead

Evolving technologies require changes in capabilities, organizational structures, prospects for market entry and exit, power structures, incentives for investment, conditions for technological learning and knowledge transfer. Domestic capabilities to adopt, adapt and master external knowledge and to gradually develop new technologies are critical to countries using the opportunities offered by new technology. Dynamic countries are either pushing for sustained leadership or assuming follower positions and seeking to skip entry barriers or escape development traps. For the largest group—laggards and even some latecomers—the ongoing technological revolution risks deepening and widening development gaps unless those countries decisively act to bridge technological and productive gaps. Development gaps may deepen and widen unless decisive efforts to bridge technological and productive capability gaps occur in both firms and countries. The overarching pledge to leave no one behind in the 2030 Agenda for Sustainable Development calls for technological solutions to local problems accessible to all.

Identifying capability gaps calls for systematic searching and learning

What works and in which contexts?

The diffusion of ADP technologies implies trial-and-error processes and great institutional variety. Flexibility and experiences of success and failure contribute meaningfully to informing policy (Freeman 1995). Informed choices about the desirable future of manufacturing-driven development require firms and governments to build on their strengths, recognize capability gaps and take risks to experiment and learn about what works and in which context. Even in front-runner economies, strategic responses remain at initial stages of implementation. Because role models are yet to emerge, policy-makers require information to shape evidence-based industrial strategies that can boost the performance of domestic agents. The complexity and systemic nature of ongoing transformations calls for enhanced policy intelligence and improved understanding of the specific barriers and drivers of change in particular sectors and technology domains (Planes-Satorra and Paunov 2019).

Learning needs structure

National strategies have to specify objectives, measurable milestones and consistent indicators subject to rigorous monitoring and evaluation. The need for clear assessment underscores the importance for learning of ongoing pilot projects carried out by diverse organizations domestically and abroad. And in follower countries, national strategies or roadmaps could improve by better identifying investment requirements (and

> Mobilizing technical centres to foster academia–industry interaction is a frequently used policy tool for knowledge sharing and awareness raising around ADPs

possible funding sources) for subsequent implementation phases. The systematic use of methodologies to benchmark performance, to carry out foresight and prospective exercises are advisable, particularly because of the multistakeholder, participatory nature of setting strategy around ADP.

Policy should improve understanding of ADP technologies and the conditions for their development, adoption and dissemination

Policy should assist economic agents in addressing expected challenges

New policy approaches should assist economic agents in addressing expected challenges, while maximizing potential benefits and minimizing risks. Horizontal interventions in education, employment and infrastructure should align with technological and productive transformations and the acquisition of new skills to access, use and master new technologies. The possibilities of winning and losing and the need for new safety nets and containment mechanisms create a particularly sensitive area in current development frameworks (Clifford 2018, Hiilamo 2019, White 2016).

Tools for assessing technologies and their possible contribution to business development

National strategies for smart manufacturing tend to be open about the technologies to be chosen and the sectors prioritized to spearhead the country's entry into the 4IR. Generally, the recommendation for countries aspiring to break into new markets for industrial goods is to actively support firms embedding "digital" in their plans. However, this should build on objective evidence. Dissemination of ADP technologies may not make sense economically for many laggard, latecomer and even follower least developed economies, at least in the short term, because of their current high factor prices and low capabilities. Adopting ADP technologies depends on their cost-effectiveness compared with existing technologies and productive processes, and on the adopter crossing minimum digital capability thresholds in several functional areas (Andreoni and Anzolin 2019). Barriers to adopting the technologies result from unawareness of how they work, what they can do, and the difficulty of comparing their benefits with those of competing, existing technologies or comparing the expected return with the perceived high upfront investment required. As documented in this report, mobilizing existing or new technical centres to foster academia–industry interaction is a frequently used policy tool among others for knowledge sharing and awareness raising around ADPs.

Both innovation and industrial policies are needed to advance ADP technologies

Manufacturing remains the locus of learning and innovation in any industrial revolution—even non-manufacturing activities, which are gaining prominence, are often connected with manufacturing (Andreoni and Anzolin 2019). Innovation policies can foster the ability to respond to demands for new design and product development. But complementary industrial policies are needed to affect the incentives and shape the capabilities of designers and producers to meet customized demands. Both innovation and industrial policies can be adapted to the challenges of an increasing digital world (Mayer 2018). Not surprisingly, leadership in developing national strategies tends to be vested with organizations responsible for industry and/or science, technology and innovation.

A pledge to further international collaboration

Further international collaboration is needed

This chapter documented the value of close collaboration among countries at different stages of readiness and adoption of smart manufacturing. The potential for expanding such collaboration is large. Most national strategies of follower countries reviewed for this report identify some frontrunner economy—such as Germany—as a preferred partner to facilitate technology transfer, human resources development and

> **International policy coordination and collaboration should continue to buttress efforts to leap forward**

joint implementation of pilot projects, and also to explore joint business models. But several other economies are available to partner with and to learn from.

Latecomer, laggard and even follower countries may wish to diversify partnerships

Latecomer, laggard and even follower countries may wish to diversify partnerships, including with other countries at similar levels of adoption of ADP technologies. Knowledge transfer can take place on a more equal footing and be closer to common realities. For instance, in the BRICS (Brazil, Russian Federation, India, China and South Africa), such collaboration is already motivating joint research and innovation on big data, ICT and other smart manufacturing technologies and their applications, and on ICT infrastructure and connectivity (BRICS Information Centre 2017).

Boost the ability to address global development challenges

Hopes are rising for rapidly evolving science, technology and innovation to help achieve several SDGs. ADP technologies are expected to boost the ability to address global development challenges and provide global public goods of economic progress, health, energy and the environment, and to expand access to such goods to otherwise deprived or excluded segments of the population (de Sousa Jabbour et al. 2018, UNCTAD 2018, UNIDO 2017c). But few national strategies make explicit the intention to contribute to achieving global development objectives. And although South Africa and Malaysia's strategies include declarations about such goals, their operationalization is pending.

Closer collaboration should be the basis of strategies

Closer collaboration should underlie strategies to address developing countries' diverging views on the challenges of ADP technologies for their progress towards inclusive and sustainable development. For example, cooperation is needed on the nature and direction of any reform to existing, or required new, regulatory and institutional frameworks to deal with issues around data, data privacy and security, and to ensure adequacy and fairness in the access to ADP technologies and the goods and services associated with them. While many of the questions are not new, the issues are becoming more pressing because of their possible implications for digital divides. Consensus on 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. The extensive review of developed economies, which generally fall in the frontrunner category, is outside the scope of this chapter. The interested reader may refer to McKinsey & Co (2017) for the United States, European Commission (2017) for various European economies, and Santiago and Horst (2018) for Germany.
2. Industry 4.0 Summit and Expo 2018 under the theme of "Vision and Development Strategy in the Fourth Industrial Revolution," July 12–13, 2018, Hanoi.
3. Sing (2017) glimpses at the complexity of public data infrastructure requirements and highlights horizontal technologies that allow general digital transactions, data architectures that protect personal privacy while enabling the collection and use of economic and social data, and core sectoral databases containing, and providing access to, digital intelligence of a given sector. These infrastructures should allow capturing value from data, and using data to govern economic activities.

Part B

Trends in industrial development indicators

Chapter 5

Industrial trends

This chapter studies the development of the world's industrial activities. It examines the evolution of manufacturing value added (MVA), the place of international trade in industrial growth, world employment trends in industry and their implications for labour productivity. Finally, the chapter presents a sectoral analysis focused on the evolution of high-technology sectors.

Evolution of world manufacturing value added

The average growth rate of world MVA for 1991–2018, 3.13 percent, was slightly higher than the growth rate of gross domestic product (GDP), 2.80 percent (Figure 5.1). The difference suggests that the manufacturing sector was a growth engine for the world economy during that period.

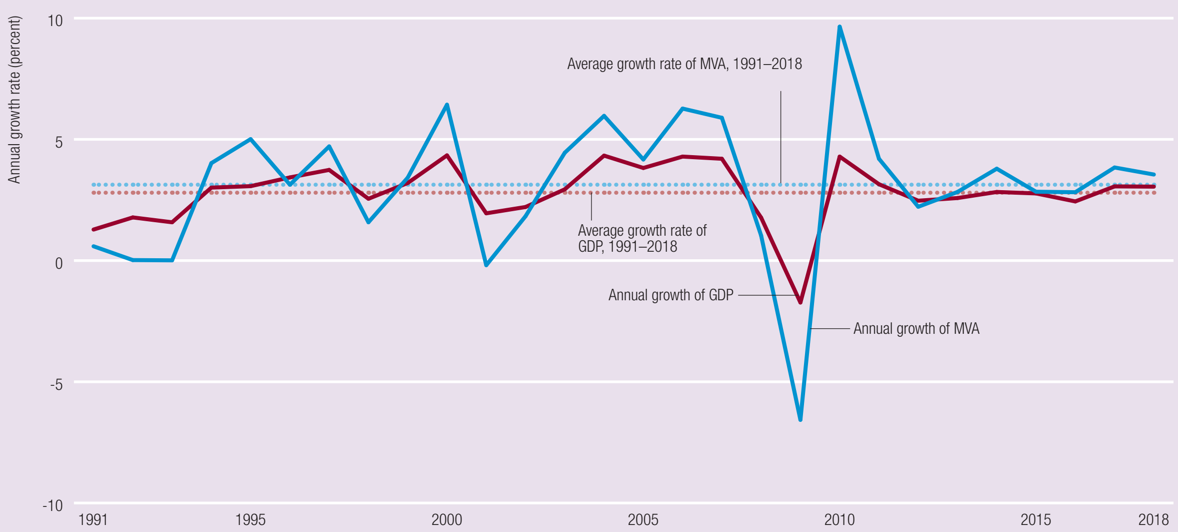
The high growth of MVA compared with GDP has expanded manufacturing's contribution to the world economy, as indicated by the increasing share of MVA in world GDP, starting at 15.2 percent in 1990 and reaching 16.4 percent in 2018 (Figure 5.2). That share has not been exempt from ups and downs directly related to the business cycles exhibited in Figure 5.1.

Figure 5.1 suggests that MVA is more volatile than GDP. When the GDP growth rates were rising, MVA growth rates were rising even higher, and when GDP growth rates were declining, MVA growth rates were declining even lower. The volatility of MVA growth results from the difficulties many countries face in sustaining long periods of industrial expansion.

Long-term economic growth was unstable over 1990–2018. The period is divided by three economic crises—during the early 1990s, 2001 and 2009—each followed by a short-lived episode of recovery and growth. Since the 2009 economic crisis—the so-called global financial crisis, followed shortly by the European debt crisis—the world economy has registered consistent growth, on average.

The post-2009 growth years have been favourable for world manufacturing, despite a tumultuous

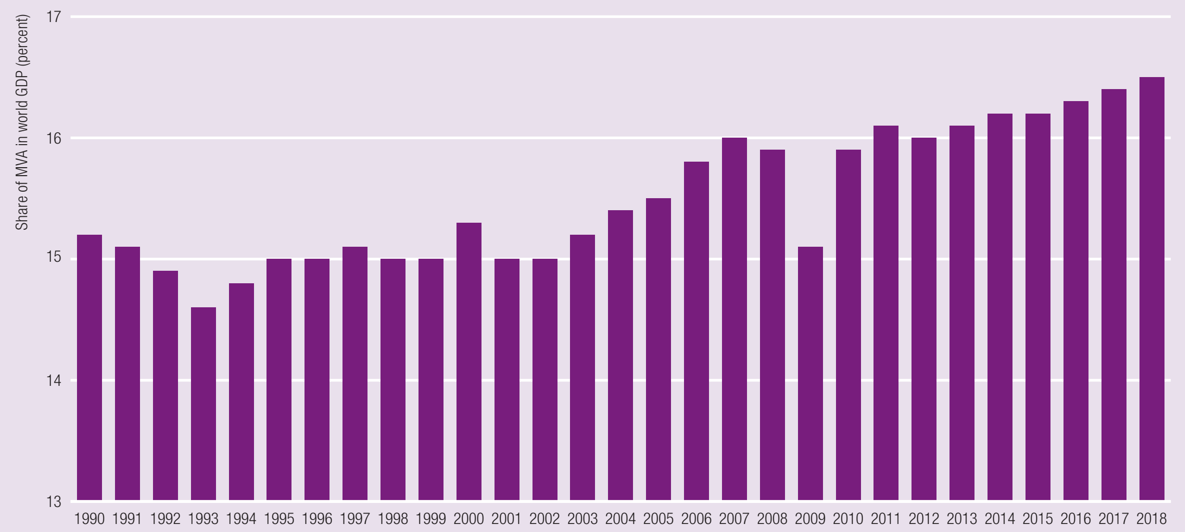
Figure 5.1
Annual growth rates of world MVA and GDP



Note: GDP is gross domestic product. MVA is manufacturing value added. All values are in constant $ 2010.
Source: UNIDO elaboration based on the Manufacturing Value Added database 2019 (UNIDO 2019g).

> **❝Chinese manufacturing increased its share in world MVA from 3 percent in 1990 to 25 percent in 2018**

Figure 5.2
Share of MVA in world GDP



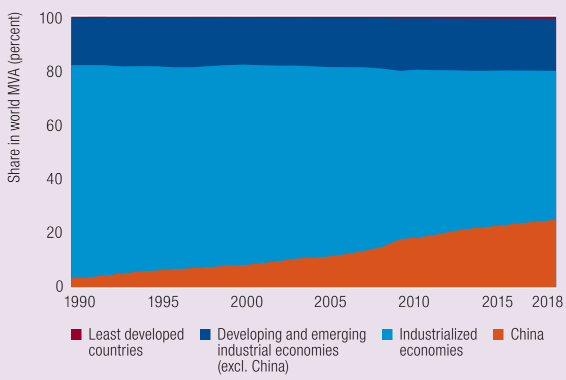
Note: GDP is gross domestic product. MVA is manufacturing value added. All values are in constant $ 2010.
Source: UNIDO elaboration based on the Manufacturing Value Added database 2019 (UNIDO 2019g).

2015–2016 characterized by high uncertainty in world markets, particularly in Europe because of the 2015 Greek debt crisis, the Brexit referendum and the aftermath of the refugee crisis. The world economy showed solid growth in the manufacturing sector, higher than the long-term MVA average (see Figure 5.1).

That trajectory mostly reflects the performance of the industrialized economies and China, which represent around 80 percent of world manufacturing production (Figure 5.3). Despite the stability of that combined share over time, the relative shares of the industrialized economies and China have changed considerably. The remarkable dynamism of the Chinese manufacturing sector increased its share in world MVA from 3 percent in 1990 to 25 percent in 2018. Conversely, the industrialized economies' share decreased from 79 percent to 55 percent during that time.

The other roughly 20 percent over 1990–2018 was jointly contributed by the developing and emerging industrial economies excluding China and the least developed countries (LDCs). But the LDCs contributed just a fraction of a percentage point, highlighting their marginalization in world manufacturing production and their low capability to integrate themselves into global production networks.

Figure 5.3
Share in world MVA by economy group

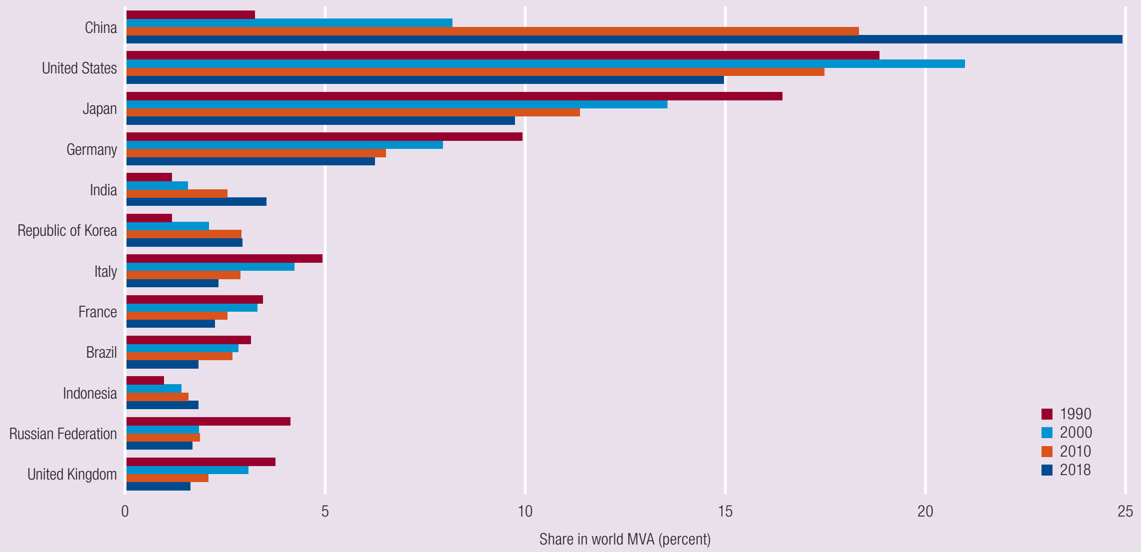


Note: MVA is manufacturing value added. All values are in constant $ 2010. Industrialization level classification is based on Annex C.1.
Source: UNIDO elaboration based on the Manufacturing Value Added database 2019 (UNIDO 2019g).

Production became increasingly concentrated from 1990 to 2018 as the 12 leading manufacturing economies' combined share of world MVA went from 71 percent to 74 percent (Figure 5.4). In 2018, only three countries—China, Japan and the United

“ Enhancing export performance requires expanding manufacturing exports

Figure 5.4
Share of the 12 largest manufacturing economies in world MVA



Note: MVA is manufacturing value added. All values are in constant $ 2010.
Source: UNIDO elaboration based on the Manufacturing Value Added database 2019 (UNIDO 2019g).

States—generated half of world manufacturing production.

The increase in China's share of world MVA stands out against the background of several developed economies performance that could not keep up. Brazil, France, Germany, Italy, Japan, Russian Federation, the United Kingdom and the United States all lost shares.

Only four of the 12 manufacturing leaders increased their share of world MVA: China, India, Indonesia and the Republic of Korea—all Asian countries. Figure 5.4 thus depicts the successful industrialization of Asian economies over the past three decades.

Evolution of world manufacturing exports

International trade has been key to economic expansion in many countries. Access to the world market allows international winners to multiply their production and profits, far beyond the possibilities their domestic economies can offer.

The past 50 years' trade increase is well documented in the economic literature. In the context of globalization, enhancing a country's export performance has become necessary to improving its economic performance. In general, enhancing export performance requires expanding manufacturing exports, since around 80 percent of world exports are manufactured.

Manufacturing exports growth is thus tightly linked to manufacturing growth and economic growth. The pattern of world manufacturing exports growth closely resembles the patterns of MVA and GDP growth (Figure 5.5). All three—manufacturing exports, MVA and GDP—suffered clear declines in growth in the early 1990s, 2001 and 2009. Yet, the patterns diverged in 2015, when exports dropped while MVA and GDP grew solidly.

The 2015 decline in manufacturing exports coincided with instability in industrialized economies—particularly in the European Union as a consequence of the 2015 Greek debt crisis—and high commodity prices, which reduced the relative price of manufactured goods compared with primary goods.

Figure 5.5 highlights the great similarity of manufacturing exports growth across all the economy groups, that is, the correlation of the manufacturing

> **Exports of medium- and high-technology goods increase with the level of countries' industrialization**

Figure 5.5
World manufacturing exports growth by economy groups

Note: All values are in current $. Industrialization level classification is based on Annex C.1.
Source: UNIDO estimations based on the United Nations Comtrade database (UNSD 2019).

exports growth series of one economy group with that of the other economy groups. The correlation suggests that trade between regions has intensified, so that when one region increased its manufacturing exports, the other regions increased theirs too, and at a similar rate, thus keeping a certain trade balance.

The correlation is even higher between the industrialized countries' manufacturing exports growth rate and the world rate—in fact, the two overlap in several years. The reason for this phenomenon is obvious: around 70 percent of manufactured exports originated in industrialized economies, so the world rate was likely to reflect their rate.

The share of manufacturing exports in economy group exports changed over 1990–2017 (Figure 5.6). As international trade intensified, developed countries gave up some manufacturing (such as car or electronics assembly), reallocating it to developing countries, which began to produce manufactured goods and export them. So, developing and emerging industrial economies and LDCs steadily increased the share of manufacturing exports in their total exports from 1990 to 2017, while industrialized economies decreased that share. By 2017, industrialized economies and developing and emerging industrial economies exhibited a similar share of manufacturing exports in their total exports.

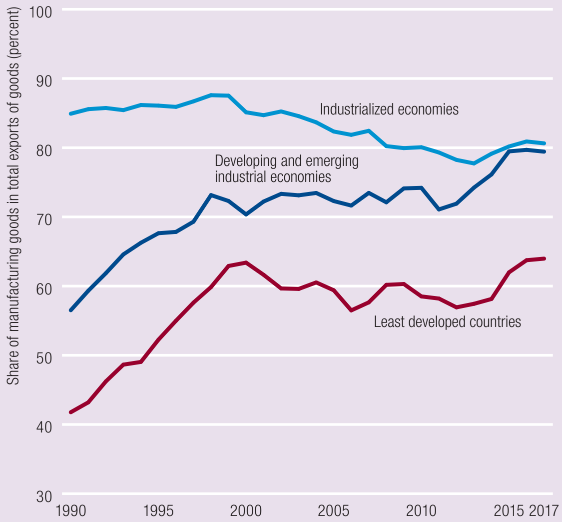
However, if China's data are separated from the rest of the developing and emerging industrial economies group, China appears as the main beneficiary of the reallocation of manufacturing production. China's share of manufacturing exports in its total exports steadily increased over 1990–2017, while the share of other developing and emerging industrial economies rose much more modestly (Figure 5.7).

Exports of medium- and high-technology goods as share of total manufacturing exports show a similar picture (Figure 5.8). The share appears to increase with the level of countries' industrialization.

China, other developing and emerging industrial economies and LDCs have increased their shares of medium- and high-technology goods in their export mix, though at different rates. While industrialized economies continue to dominate international markets, China is quickly catching up and has almost matched the industrialized economies. Other developing and emerging industrial economies have also been closing the gap with industrial leaders, but more

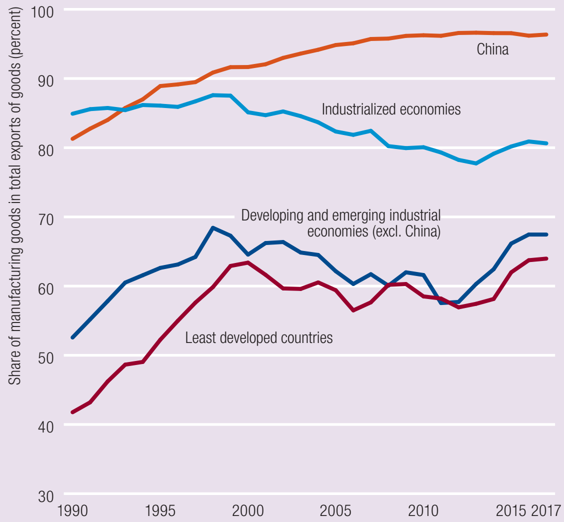
China's share of manufacturing exports in its total exports steadily increased over 1990–2017

Figure 5.6
Manufacturing exports as a share of total exports by economy group



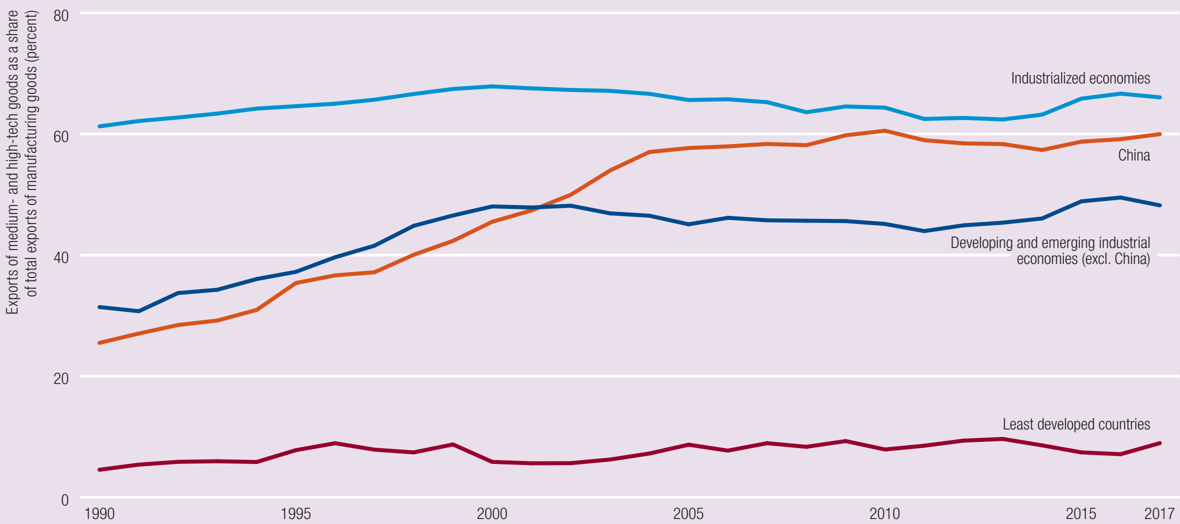
Note: All values are in current $. Industrialization level classification is based on Annex C.1.
Source: UNIDO elaboration based on the United Nations Comtrade database (UNSD 2019).

Figure 5.7
Manufacturing exports as a share of total exports by economy group, with China separated



Note: All values are in current $. Industrialization level classification is based on Annex C.1.
Source: UNIDO elaboration based on the United Nations Comtrade database (UNSD 2019).

Figure 5.8
Exports of medium- and high-technology goods as a share of total manufacturing exports by economy group



Note: All values are in current $. Industrialization level classification is based on Annex C.1. The technological classification of manufacturing activities is based on Annex C.2.
Source: UNIDO elaboration based on the United Nations Comtrade database (UNSD 2019).

slowly, and today remain a considerable distance behind the industrialized economies. Finally, LDCs have also increased the share of high-technology exports in their total manufacturing exports, but that share continues to be much smaller than those of the other economy groups.

> **Manufacturing sector employment increased 0.9 percent a year on average from 1992 to 2018**

Evolution of world manufacturing employment

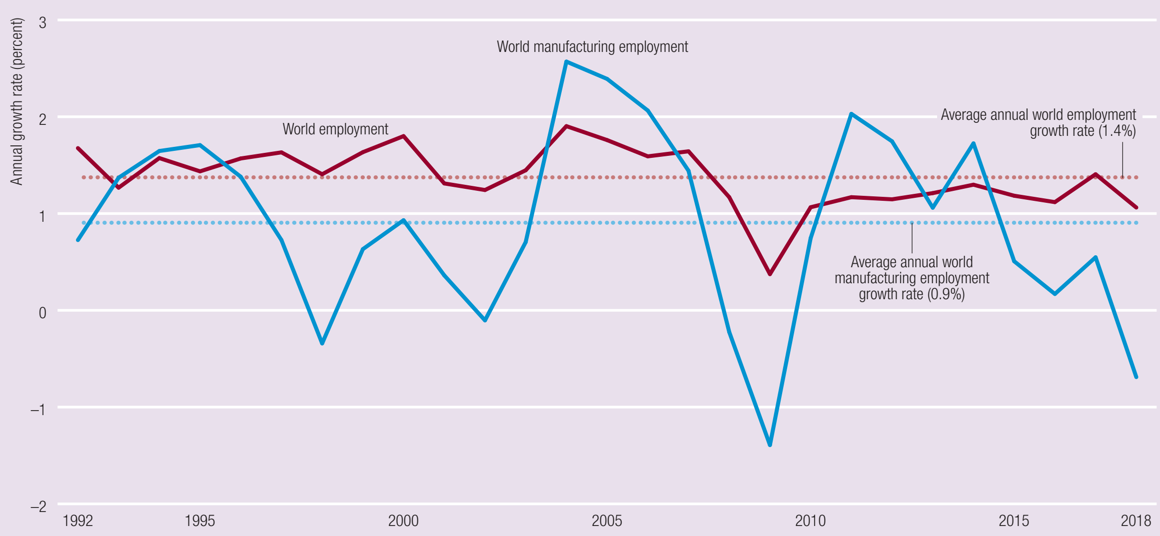
Increased manufacturing production has generally been accompanied by increased labour demand. So, manufacturing sector employment also increased—around 0.9 percent a year on average from 1992 to 2018 (Figure 5.9). Its growth has been volatile, though positive on average. The fluctuation seems to relate directly to world MVA: employment growth has declined whenever MVA growth rate has declined.

But the relationship seems to have weakened between MVA and manufacturing employment in recent years. While world MVA growth was fairly stable around its average from 2011 to 2018, growth in world manufacturing employment slowed, turning negative in 2018. The 2018 employment growth rate was the second-worst of the 1992–2018 period, −0.7 percent, surpassed only by the −1.4 percent rate during the 2009 economic crisis.

The conjunction of a fall of manufacturing employment growth with solid MVA growth means an increase in labour productivity in manufacturing, probably related to the rapid absorption of new technologies (see next section). When this productivity increase is higher than in other sectors of the economy and it occurs simultaneously with an increase in the MVA share in GDP, it implies a decline in the share of manufacturing in total employment, as observed in Figure 5.10. Indeed, the highest share was reached at the beginning of the period (16.1 percent), and then it gradually declined to its lowest value, 14.2 percent, in 2018.

The declining share of manufacturing in world total employment cannot be fully understood without examining whether manufacturing employment was created in economy groups where manufacturing production was increasing. Figure 5.3 suggested that over 1990–2018, the economy groups' shares in world MVA were stable and that while LDCs and developing and emerging industrial economies (excluding China) held steady at around 20 percent of world MVA, China and the industrialized economies jointly held a roughly constant share of 80 percent. The most notable change was China's increasing share, which went from 3 percent to 25 percent, while the industrialized economies' share decreased from 79 percent to 55 percent.

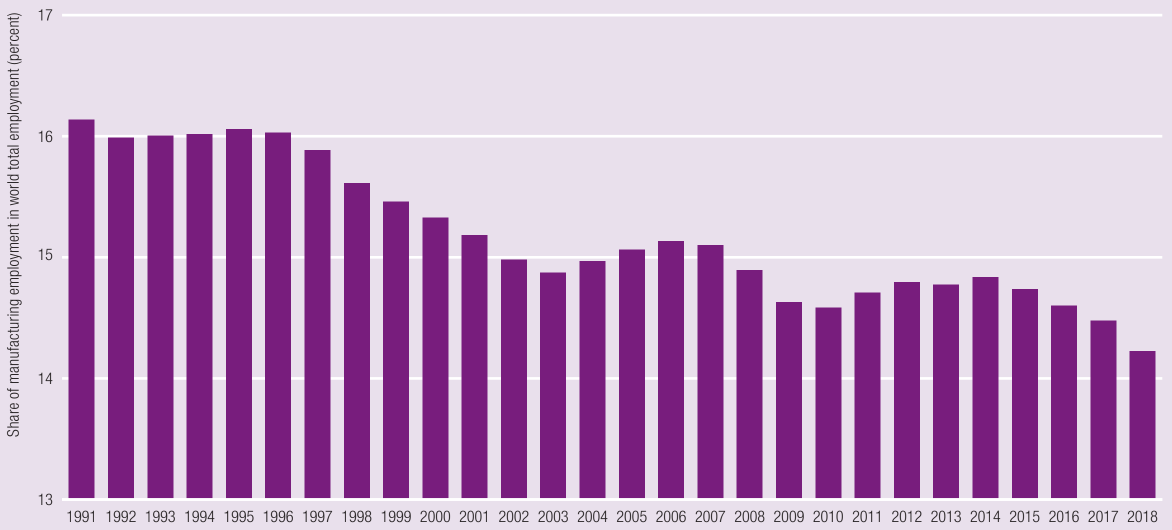
Figure 5.9
Annual growth rates of world manufacturing employment and world total employment



Source: UNIDO elaboration based on ILO (2018).

"Most manufacturing employment growth occurred in developing and emerging industrial economies

Figure 5.10
Share of manufacturing employment in world total employment



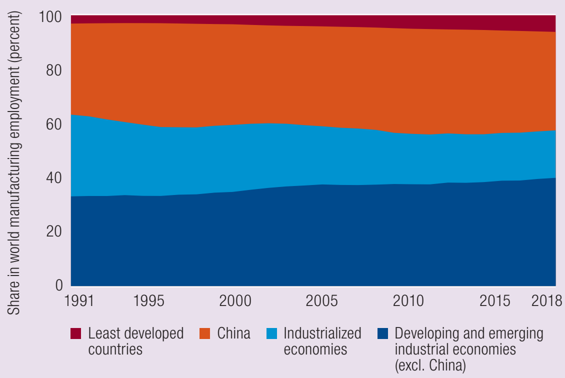
Source: UNIDO elaboration based on ILO (2018).

But most manufacturing employment growth occurred in developing and emerging industrial economies (excluding China)—in contrast to their stable share of world MVA. They increased their share in world manufacturing employment from 33.1 percent in 1991 to 40.0 percent in 2018 (Figure 5.11). China's share increased from 33.6 percent to 36.4 percent and LDCs' share from 3.1 percent to 6.1 percent. The industrialized economies share dropped from 30.2 percent to 17.5 percent.

The declining employment share in industrialized economies is not surprising, since their share of world MVA also fell. But a disproportionate increase in share of world employment took place in developing and emerging industrial economies (excluding China), whose share of world MVA was roughly constant. Conversely, China, which unquestionably thrived in its share of world MVA, increased its share of world employment only moderately, like the LDCs.

The differences across the economy groups between the world MVA share and world employment share trends suggest that the economy groups followed different paths in adopting technology and increasing labour productivity.

Figure 5.11
Share in world manufacturing employment by economy group



Note: Industrialization level classification is based on Annex C.1.
Source: UNIDO elaboration based on ILO (2018).

Evolution of the world's manufacturing labour productivity

Changes in MVA per worker—that is, in manufacturing labour productivity—result from changes in MVA and manufacturing employment. When value added expands faster than employment, labour productivity rises. By contrast, when value added drops and employment increases, labour productivity declines.

> **During 1991–2018, labour productivity in the manufacturing sector grew faster than in the total economy**

5

INDUSTRIAL TRENDS

The preceding discussion showed that during 1991–2018, the world manufacturing value added grew faster than the total economy (see Figure 5.1). But world manufacturing employment grew slower than total world employment (see Figure 5.9). So, labour productivity in the manufacturing sector grew faster than in the total economy (Figure 5.12).

World productivity in manufacturing grew faster—83 percent—than world productivity overall—48 percent—over 1991–2018. Productivity often indicates innovation and technical change, so manufacturing's higher productivity attests to manufacturing's function as the catalyst for innovation and technological change and its status as the economic sector where most innovations are created and introduced.

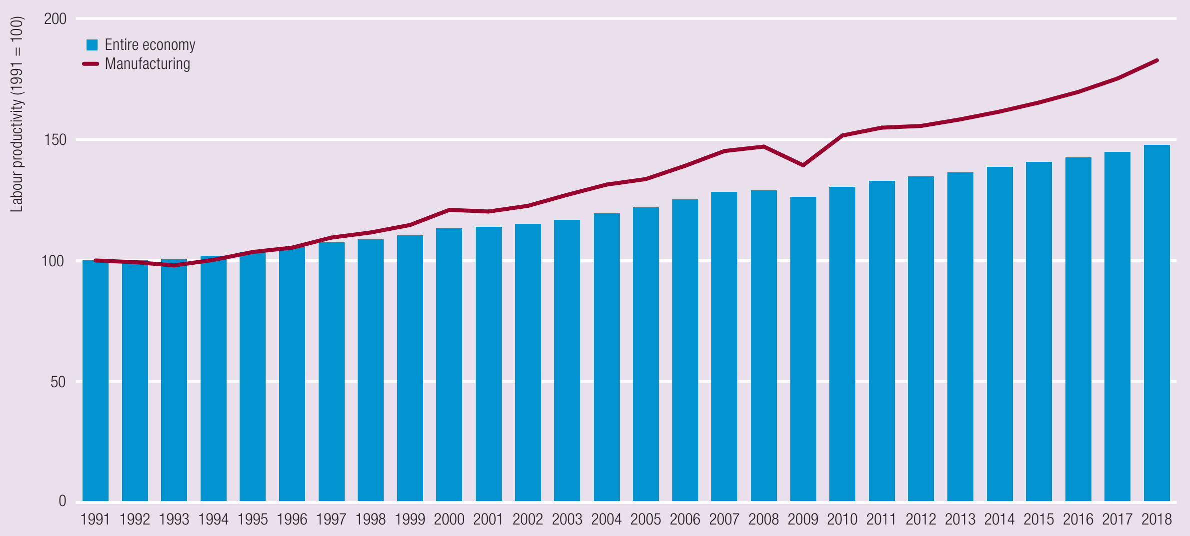
Innovation differs greatly across countries. Although a few countries push the technological frontier forward with innovations, the vast majority focus on copying and adapting technologies to their own needs. Given the strong relationship between innovation and productivity, does productivity show the same disparity as innovation across countries?

The group of industrialized economies was the closest to the technological frontier in manufacturing labour productivity, using the United States as a proxy for the frontier (Figure 5.13). That group's gap with the United States grew slightly from 1991 to 2018, as its productivity sank from 80.1 percent of U.S. productivity to 73.8 percent. The developing and emerging industrial economies productivity fell from 16.2 percent of U.S. productivity to 11.3 percent, and the LDCs' productivity fell from 4.7 percent of U.S. productivity to 2.9 percent.

World manufacturing labour productivity grew around 2.3 percent a year over 1992–2018. Industrialized economies' growth averaged around 3 percent a year, despite their reduced share of world MVA, higher than the world average and slightly higher than the 2 percent growth of developing and emerging industrial economies. LDCs reported the lowest productivity growth, 1.5 percent a year on average.

China's manufacturing labour productivity growth rates were considerably higher than the world average and other economy group rates from 1992

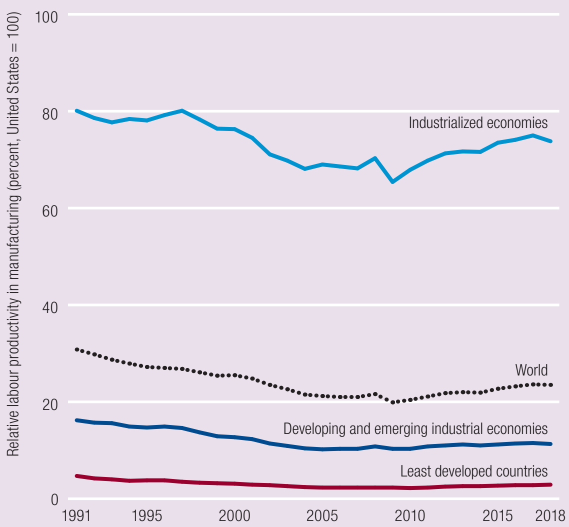
Figure 5.12
World labour productivity in manufacturing and in the entire economy



Note: Labour productivity is calculated as the value added per worker (in constant $ 2010).
Source: UNIDO elaboration based on the Manufacturing Value Added database 2019 (UNIDO 2019g) and ILO (2018).

" Manufacturing's higher productivity attests to its status as the economic sector where most innovations are created and introduced

Figure 5.13
Labour productivity in manufacturing relative to U.S. productivity by economy group



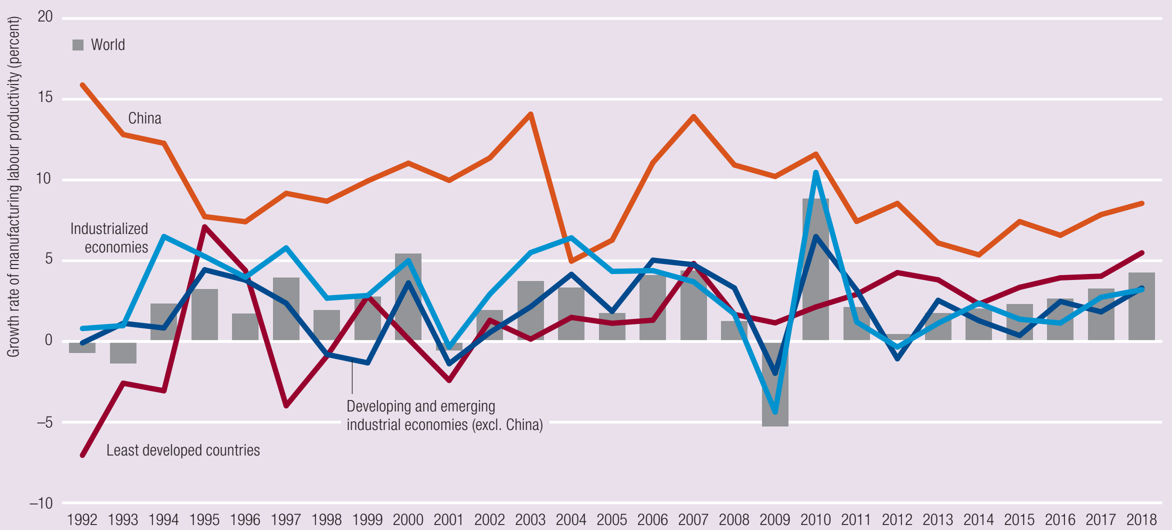
Note: Labour productivity is calculated as the value added per worker (in constant $ 2010). Industrialization level classification is based on Annex C.1.
Source: UNIDO elaboration based on the Manufacturing Value Added database 2019 (UNIDO 2019g) and ILO (2018).

to 2018, averaging 9.5 percent a year within a range of 5 percent to 16 percent (Figure 5.14). China's rate slowed moderately towards the end of the period, coinciding with improved wages and living conditions in the country. Even at its lowest level, Chinese productivity growth was higher than the world average.

The differences in productivity growth across economy groups—which result from employment and MVA trends—seem to depict a clear division. Industrialized economies, with state-of-the-art technology in their productive units, have given away their labour-intensive operations to other countries while keeping the more knowledge-intensive ones. The industrialized economies are already highly productive and are the fastest to adopt the technology they produce, pushing the technological frontier even further and removing themselves far from the rest of the world.

The developing and emerging industrial economies, with most productive units presenting different degrees of technological backwardness, still use low wages as an advantageous entry point for their integration into the global markets. The developing and emerging industrial economies adopt new technologies after some delay, and their productivity typically grows slightly slower than that of the industrialized economies.

Figure 5.14
Manufacturing labour productivity growth rates by economy group



Note: Labour productivity is calculated as the value added per worker (in constant $ 2010). Industrialization level classification is based on Annex C.1.
Source: UNIDO elaboration based on the Manufacturing Value Added database 2019 (UNIDO 2019g) and ILO (2018).

> **Structural change towards technology-intensive sectors promotes the development of innovative activities**

Table 5.1
Economy group shares in manufacturing goods at different technology levels

	2005	2010	2015	2016	2017
Low-technology					
Industrialized economies	67.5	59.1	53.0	52.6	51.8
Developing and emerging industrial economies (excluding China)	24.5	26.3	26.8	26.6	26.6
Least developed countries	0.6	0.9	1.3	1.3	1.4
China	7.4	13.7	19.0	19.5	20.2
Total	100.0	100.0	100.0	100.0	100.0
Medium-low-technology					
Industrialized economies	68.4	59.3	53.5	52.9	52.8
Developing and emerging industrial economies (excluding China)	22.7	24.1	23.2	23.1	23.1
Least developed countries	0.2	0.3	0.4	0.4	0.4
China	8.6	16.3	22.9	23.6	23.7
Total	100.0	100.0	100.0	100.0	100.0
Medium-high- and high-technology					
Industrialized economies	78.7	70.7	65.3	64.1	63.2
Developing and emerging industrial economies (excluding China)	14.3	15.8	15.4	15.3	15.3
Least developed countries	0.1	0.1	0.1	0.1	0.1
China	7.0	13.5	19.2	20.5	21.4
Total	100.0	100.0	100.0	100.0	100.0

Note: Each value represents the percentage share of an economy group in the global manufacturing value added (MVA) of the sectors corresponding to a specific technology level. See Annex C.1 for the economy group classification and Annex C.2 for the technological classification of manufacturing activities. MVA is in constant $ 2010.
Source: UNIDO estimation based on UNIDO (2019f).

Growth in labour productivity, though serving as a proxy for innovation, does not provide all the information needed to evaluate the technological and productive capabilities of a country or group of countries. That is because technological and productive capabilities are linked to structural change, with different manufacturing sectors differing in their contribution to innovation and growth.

Sectoral analysis of world manufacturing value added

Sectoral analysis is needed because sectors do not contribute evenly to the expansion of technological and productive capabilities. A country's specialization in low-tech sectors may hinder the growth of its technological capabilities, prevent sustainable economic growth and permanently reduce long-run welfare (UNIDO 2013, 2015). By contrast, structural change towards technology-intensive sectors will increase local demand for technical knowledge and engineering services, promote the development of innovative activities and spread their positive externalities across the whole productive system.

In other words, specialization in producing goods with a low-knowledge, low-technology content reduces the creation and dissemination of local knowledge at a sectoral, national and regional level. Specialization in producing knowledge-intensive, high-technology goods produces synergies in the economic system and increase overall productivity. Specialization patterns thus shape further economic characteristics and account for phases of relative technological success and failure. Structural change that moves resources towards knowledge-intensive, high-technology goods will be positive, while countries persistently specializing in low-tech sectors can be expected to have comparatively limited technological and production capabilities (Cimoli and Correa 2005).

“Accelerated technical change has changed the structure of goods being produced

Industrialized economies dominated the production of medium-high-tech and high-tech goods from 2005 to 2017, even while their share in world MVA decreased from 78.7 percent to 63.2 percent (Table 5.1; see Figure 5.3). At all technology levels of goods —low, medium and high—industrialized economies led in the concentration of MVA and experienced a decrease over the period. Similarly, at all technology levels of goods, China increased its share of world MVA at the expense of the industrialized economies. Developing and emerging industrial economies had a stable share that increased slightly. LDCs expanded their share, but only in low- and medium-low-technology goods. In sum, economy group shares in world MVA were fairly stable across the technology levels of goods.

Accelerated technical change has changed the structure of goods being produced. World manufacturing is producing more sophisticated goods, characterized by higher knowledge content and requiring more advanced and complex production techniques. The share of medium-high- and high-technology goods in world MVA increased from 42.2 percent in 2005 to 45.6 percent in 2017 (Table 5.2). The share of low-technology goods in world MVA fell from 30.7 percent to 28.6 percent, and the share of medium-low-technology goods from 27.1 percent to 25.8 percent. Similar changes took place in all economy groups except LDCs, which slightly increased their share of low-technology products in MVA, highlighting the technological fragilities of these economies as their technological gap with the rest of the manufacturing world expanded.

Table 5.2
Technology level of goods by economy group

	2005	2010	2015	2016	2017
Industrialized economies					
Low-technology	28.6	27.4	26.2	26.3	25.9
Medium-low-technology	25.6	24.3	23.9	23.9	23.8
Medium-high- and high-technology	45.9	48.3	49.9	49.8	50.3
Total	100.0	100.0	100.0	100.0	100.0
Developing and emerging industrial economies					
Low-technology	35.9	33.6	32.4	32.0	31.7
Medium-low-technology	31.1	30.0	29.6	29.3	28.7
Medium-high- and high-technology	33.0	36.3	37.9	38.6	39.6
Total	100.0	100.0	100.0	100.0	100.0
Least developed countries					
Low-technology	70.1	70.4	70.9	70.7	70.8
Medium-low-technology	21.6	20.5	19.7	18.9	19.2
Medium-high- and high-technology	8.3	9.1	9.4	10.4	10.0
Total	100.0	100.0	100.0	100.0	100.0
World					
Low-technology	30.7	29.8	29.0	28.9	28.6
Medium-low technology	27.1	26.3	26.2	26.1	25.8
Medium-high- and high-technology	42.2	43.9	44.8	44.9	45.6
Total	100.0	100.0	100.0	100.0	100.0

Note: Each value represents the percentage share of a specific technology level in the total manufacturing value added (MVA) of an economy group. See Annex C.1 for the economy group classification and Annex C.2 for the technological classification of manufacturing activities. MVA is in constant $ 2010.
Source: UNIDO estimation based on UNIDO (2019f).

Chapter 6

The Competitive Industrial Performance Index

The Competitive Industrial Performance Index

Industrial competitiveness is key to inclusive and sustainable industrial development (ISID). It shapes sectoral specialization and consequent structural change. It thus also determines the contribution of industry to overall prosperity and long-run sustainable growth.

UNIDO assesses and benchmarks industrial competitiveness through its Competitive Industrial Performance (CIP) Index. This index measures how much a country's manufacturing sector contributes to development—how well industries produce goods, sell them on domestic and foreign markets and thus contribute to structural change (UNIDO 2019b).

The CIP Index covers three main dimensions. The higher the score on any dimension, the higher the country's industrial competitiveness and its CIP Index (Figure 6.1):

- *Capacity to produce and export manufactured goods.* This dimension provides a comparable measure of a country's manufacturing production for either local or foreign consumption. It is assessed by (1) manufacturing value added (MVA) per capita and (2) manufacturing exports per capita
- *Technological deepening and upgrading.* This dimension assesses the types of goods a country's manufacturing sector produces. Because technology-intensive goods create technological spillovers and reduce vulnerability to price shocks, producing them and, further, exporting them is rated as having higher expected benefits than producing lower-tech goods. This dimension is taken into account by (1) industrialization intensity, which captures the role and technological complexity of a country's production and (2) export quality, which captures the technological complexity of the export bundle.
- *World impact.* The more a country participates in global markets, the higher its ability to benefit from agglomeration and scope and scale effects, perhaps attracting shared infrastructure investments and expanding trade agreement negotiating power. The world impact dimension is measured by the country's impact on (1) world MVA and (2) world manufacturing exports.

The CIP Index can assess a country's industrial performance across the three dimensions and benchmark it against the country's direct competitors or regional neighbours. By highlighting areas in which other countries achieve higher CIP scores, the index can guide policies for future development. Or by analysing the manufacturing sectors of countries that perform poorly, it can highlight inefficiencies in allocating factors of production, such as labour and capital.

The CIP Index offers an intuitive starting point for more detailed analyses to identify inefficiencies. It thus helps a country pursue widespread productivity growth and structural change by highlighting targets determined by a country's circumstances. Since structural change is long term, changes in the country's CIP Index are likely to follow the implementation of policies to increase competitiveness by several years.

Identifying a country's competitors leads to drawing policy implications. This chapter, after presenting the main CIP results, examines them by geographical region and by stage of industrialization. Although the competitors should be identified one by one based on such factors as geographical distance, the type of good produced, the availability of production factors and whether competition is actual or potential, such analysis goes beyond the scope of the chapter. It concludes by relating the CIP Index and Sustainable Development Goal (SDG) 9: "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation."

Main results

Table 6.1 ranks economies by their composite score on the 2019 CIP Index, using 2017 data—the latest available. The table groups economies into index

> **Industrial competitiveness is key to inclusive and sustainable industrial development**

Figure 6.1
Dimensions of the CIP Index

Source: UNIDO (2017c).

quintiles—top, upper middle, middle, lower middle and bottom.[1] It depicts each economy's stage of development—least developed countries (LDCs), other developing economies, emerging industrial economies and industrialized economies. The stage of development and competitiveness are correlated. The top quintile of the CIP Index consists almost entirely of industrialized economies, while the majority of LDCs are concentrated in the bottom quintile. There are some exceptions, however. For example, the Philippines and Viet Nam are both classified as other developing economies, yet they perform better on the CIP Index than several industrialized economies and emerging industrial economies and are ranked in the upper middle quintile of the CIP.

Figure 6.2 presents the scores and ranks of the top performing economies in the 2019 CIP Index. Germany achieved the highest composite score and thus ranks first—as it has for all years but one since 1990. Ranking second through fifth are Japan, China (surging from 22nd in 2000), the Republic of Korea and the United States. Figure 6.2 also shows the economies setting the competitiveness benchmarks in five geographic regions and four development groups.

Although the CIP Index can range up to 1, the highest score—Germany's—is only 0.5. This reflects the fact that no country leads on all CIP dimensions.

“The top quintile of the CIP Index consists almost entirely of industrialized economies; Germany, with the highest composite score, ranks first

Table 6.1
2019 CIP Index

■ Industrialized economies ■ Emerging industrial economies ■ Other developing economies ■ Least developed countries

Quintile	Rank 2017	Country	Score 2017	Rank 2015	Change in rank, 2015–2017
Top quintile	1	Germany	0.5146	1	
	2	Japan	0.4043	2	
	3	China	0.3687	3	
	4	Republic of Korea	0.3646	5	▲
	5	United States of America	0.3551	4	▼
	6	Ireland	0.3237	7	▲
	7	Switzerland	0.3119	6	▼
	8	Belgium	0.2716	8	
	9	Italy	0.2690	9	
	10	Netherlands	0.2687	11	▲
	11	France	0.2605	10	▼
	12	Singapore	0.2563	12	
	13	Taiwan Province of China	0.2394	13	
	14	Austria	0.2242	14	
	15	Czech Republic	0.2153	18	▲
	16	Sweden	0.2076	17	▲
	17	United Kingdom	0.2070	15	▼
	18	Canada	0.2038	16	▼
	19	Spain	0.2009	19	
	20	Denmark	0.1754	21	▲
	21	Malaysia	0.1664	22	▲
	22	Mexico	0.1662	20	▼
	23	Poland	0.1649	23	
	24	Slovakia	0.1589	25	▲
	25	Finland	0.1481	26	▲
	26	Hungary	0.1459	27	▲
	27	Thailand	0.1458	24	▼
	28	Turkey	0.1343	28	
	29	Israel	0.1243	29	
	30	Australia	0.1152	30	
Upper middle quintile	31	Russian Federation	0.1086	31	
	32	Romania	0.1084	33	▲
	33	Slovenia	0.1066	35	▲
	34	Portugal	0.1020	34	
	35	Brazil	0.0975	36	▲
	36	Norway	0.0970	32	▼
	37	Saudi Arabia	0.0951	37	
	38	Indonesia	0.0892	38	
	39	India	0.0844	39	

(continued)

"Ranking second through fifth are Japan, China, the Republic of Korea and the United States

Table 6.1 *(continued)*
2019 CIP Index

Quintile	Rank 2017	Country	Score 2017	Rank 2015	Change in rank, 2015–2017
Upper middle quintile	40	Lithuania	0.0830	40	
	41	Philippines	0.0728	43	▲
	42	United Arab Emirates	0.0720	41	▼
	43	Viet Nam	0.0713	46	▲
	44	Luxembourg	0.0691	42	▼
	45	South Africa	0.0680	44	▼
	46	Belarus	0.0669	45	▼
	47	New Zealand	0.0644	48	▲
	48	Estonia	0.0633	49	▲
	49	Islamic Republic of Iran	0.0616	53	▲
	50	Greece	0.0608	52	▲
	51	Argentina	0.0606	47	▼
	52	Chile	0.0602	51	▼
	53	Qatar	0.0578	50	▼
	54	Croatia	0.0550	56	▲
	55	Bulgaria	0.0541	58	▲
	56	Bahrain	0.0494	55	▼
	57	Latvia	0.0473	59	▲
	58	Trinidad and Tobago	0.0465	57	▼
	59	Kuwait	0.0444	54	▼
	60	Peru	0.0431	61	▲
Middle quintile	61	Morocco	0.0425	60	▼
	62	Serbia	0.0411	65	▲
	63	Tunisia	0.0396	62	▼
	64	Malta	0.0385	66	▲
	65	Costa Rica	0.0382	67	▲
	66	Kazakhstan	0.0375	68	▲
	67	Ukraine	0.0373	69	▲
	68	Oman	0.0363	63	▼
	69	Bolivarian Republic of Venezuela	0.0354	64	▼
	70	Colombia	0.0352	70	
	71	Egypt	0.0338	72	▲
	72	Bangladesh	0.0336	73	▲
	73	Iceland	0.0313	71	▼
	74	North Macedonia	0.0299	79	▲
	75	El Salvador	0.0295	76	▲
	76	Guatemala	0.0294	75	▼
	77	Sri Lanka	0.0290	78	▲
	78	Panama	0.0285	74	▼
	79	Uruguay	0.0273	77	▼
	80	Bosnia and Herzegovina	0.0264	82	▲

(continued)

“Asia and Pacific includes three of the top four countries on the CIP ranking

Table 6.1 *(continued)*
2019 CIP Index

Quintile	Rank 2017	Country	Score 2017	Rank 2015	Change in rank, 2015–2017
Middle quintile	81	Eswatini	0.0256	81	
	82	Jordan	0.0250	80	▼
	83	Pakistan	0.0240	83	
	84	Lebanon	0.0226	91	▲
	85	Brunei Darussalam	0.0220	87	▲
	86	Mauritius	0.0214	88	▲
	87	Hong Kong SAR, China	0.0207	85	▼
	88	Botswana	0.0205	86	▼
	89	Cambodia	0.0203	90	▲
	90	Myanmar	0.0202	97	▲
Lower middle quintile	91	Ecuador	0.0193	89	▼
	92	Cyprus	0.0165	95	▲
	93	Honduras	0.0158	93	
	94	Georgia	0.0154	96	▲
	95	Algeria	0.0153	94	▼
	96	Côte d’Ivoire	0.0149	101	▲
	97	Namibia	0.0146	92	▼
	98	Paraguay	0.0138	98	
	99	Armenia	0.0133	104	▲
	100	Plurinational State of Bolivia	0.0130	99	▼
	101	Jamaica	0.0119	100	▼
	102	Nigeria	0.0114	84	▼
	103	Lao People’s Democratic Rep	0.0110	105	▲
	104	Congo	0.0105	114	▲
	105	Suriname	0.0100	106	▲
	106	Republic of Moldova	0.0098	111	▲
	107	Mongolia	0.0097	102	▼
	108	Barbados	0.0097	108	
	109	Albania	0.0096	109	
	110	Senegal	0.0093	113	▲
	111	State of Palestine	0.0093	110	▼
	112	Kenya	0.0093	107	▼
	113	Gabon	0.0092	112	▼
	114	Fiji	0.0092	116	▲
	115	Azerbaijan	0.0090	103	▼
	116	Syrian Arab Republic	0.0087	115	▼
	117	Cameroon	0.0083	117	
	118	Kyrgyzstan	0.0075	121	▲
	119	Bahamas	0.0072	120	▲
	120	Montenegro	0.0067	124	▲

(continued)

> **“The CIP dimensions are path-dependent, so a country must make a continuous effort to move up in the rankings**

Table 6.1 *(continued)*
2019 CIP Index

Quintile	Rank 2017	Country	Score 2017	Rank 2015	Change in rank, 2015–2017
Bottom quintile	121	Zambia	0.0066	118	▼
	122	Papua New Guinea	0.0061	123	▲
	123	Ghana	0.0058	122	▼
	124	Zimbabwe	0.0054	125	▲
	125	Belize	0.0053	127	▲
	126	Madagascar	0.0052	126	
	127	United Republic of Tanzania	0.0047	119	▼
	128	Central African Republic	0.0046	131	▲
	129	Tajikistan	0.0041	130	▲
	130	Uganda	0.0041	128	▼
	131	Angola	0.0036	133	▲
	132	Nepal	0.0036	132	
	133	Mozambique	0.0035	129	▼
	134	Saint Lucia	0.0031	136	▲
	135	Cabo Verde	0.0031	138	▲
	136	Bermuda	0.0029	139	▲
	137	Haiti	0.0028	135	▼
	138	Malawi	0.0023	134	▼
	139	Rwanda	0.0022	141	▲
	140	Yemen	0.0017	140	
	141	Ethiopia	0.0016	148	▲
	142	Maldives	0.0016	144	▲
	143	Afghanistan	0.0012	143	
	144	Niger	0.0009	137	▼
	145	Macao SAR, China	0.0008	145	
	146	Iraq	0.0006	142	▼
	147	Gambia	0.0004	146	▼
	148	Burundi	0.0000	147	▼
	149	Eritrea	0.0000	149	
	150	Tonga	0.0000	150	

Source: UNIDO elaboration based on the Competitive Industrial Performance Index 2019 database (UNIDO 2019c).

CIP scores are distributed very unequally across the dimensions, and few economies achieve high scores.

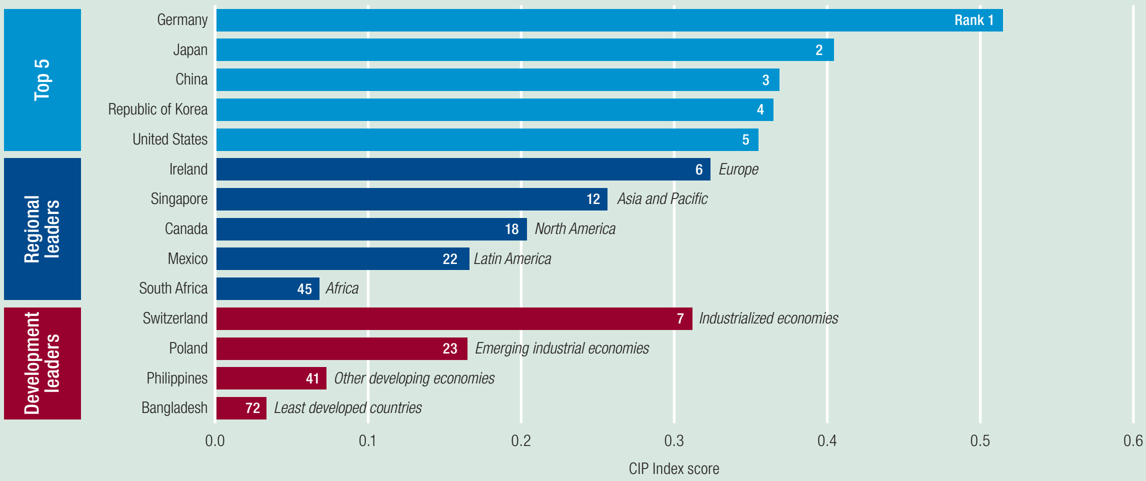
Results by geographical region and development stage

Although the overall CIP ranking provides a quick indication of a country’s industrial competitiveness compared with other countries, it tells nothing more about the strengths and weaknesses of the country’s industrial system. Detailed analysis of a country’s performance on the three CIP dimensions is necessary to get a deeper understanding.

In general, the CIP dimensions are path-dependent, so a country must make a continuous effort to expand its industrial capabilities and move up in the rankings, which reflect its success or failure in

“Changes in yearly observations may provide policymakers timely insights into the effectiveness of current strategies

Figure 6.2
Scores and ranks of the top CIP performing economies in 2017



Note: CIP is Competitive Industrial Performance. “Regional leaders” and “development leaders” are runners-up if the top country in the region or development stage already appears among the top 5. See Annex C.1 for the economy group classification.
Source: UNIDO elaboration based on the Competitive Industrial Performance Index 2019 database (UNIDO 2019c).

expanding competitiveness in comparison with other countries. The development of each dimension can take several years, so major movements seldom occur quickly. But small changes in yearly observations may provide policy-makers with timely insights into the direction of change and the effectiveness of current industrial strategies.

Europe is the leading region on all three CIP dimensions (Table 6.2).[2] Europe excels on capacity to produce and export manufactures. In 2017, European countries ranked 37th on average on this CIP dimension, while North American countries, the immediate followers, ranked 49th. But the difference is much smaller on the world impact dimension, where European countries rank 52nd on average, and North American countries rank 54th. In other words, while European countries produce and export considerably more manufactured goods per capita than their North American counterparts, they participate similarly in world markets, with high integration.

Latin America and Asia and Pacific follow Europe and North America at some distance. Latin America and Asia and Pacific are similar to each other in competitiveness, Latin America doing slightly better on the first dimension, and Asia and Pacific on the second and third dimensions. The largest difference is the diversity of the groups of economies that make up each region. Asia and Pacific is the most diverse. It includes three of the top four countries on the CIP ranking (China, Japan and the Republic of Korea) and the top-ranking country on both the second dimension (Republic of Korea) and the third dimension (China). But the region also contains many countries in the bottom quintile, including the very last: Tonga.

With such diversity, the Asia and Pacific average does not present a clear picture. The region has two poles of industrial competitiveness. One pole includes top industrial economies that can compete with any others. But the other pole includes economies at an early stage in their industrial development.

The African region ranks last because its industrial leaders—Egypt, Morocco, South Africa and Tunisia—cannot pull the rest of the region along. It has the highest presence of economies belonging to the bottom quintile of the CIP ranking, which overlap with the countries at the lowest level of development—the LDCs.

> **The level of industrialization is central to SDG 9**

Table 6.2
CIP rankings on the three dimensions of industrial competitiveness by geographical region and industrialization level

Economy groups	Capacity to produce and export manufactures (1st dimension) 2015	2017	Technological deepening and upgrading (2nd dimension) 2015	2017	World impact (3rd dimension) 2015	2017	Overall rank 2015	2017
Geographical regions (averages)								
Europe	38	37	42	42	53	52	43	42
North America	50	49	51	52	54	54	53	53
Asia and Pacific	81	81	80	80	74	73	76	76
Latin America	79	80	86	84	84	84	83	83
Africa	116	116	106	107	103	104	112	113
Development stages (averages)								
Industrialized economies	27	27	42	42	43	43	34	34
Emerging industrial economies	63	62	60	60	54	53	56	55
Other developing economies	101	101	101	99	101	101	103	103
Least developed countries	135	134	110	112	116	117	126	127

Note: CIP is Competitive Industrial Performance. See Annex B.1 for the country-level rankings on the three CIP dimensions. See Annex C.1 for the economy group classification.
Source: UNIDO elaboration based on the Competitive Industrial Performance Index 2019 database (UNIDO 2019c).

At each development stage, the ranking of the economy groups is fairly clear and unsurprising. There are exceptions—countries that perform unexpectedly well (or badly) for the group they belong to—but as exceptions they only confirm that, on average, industrialized economies are more competitive than emerging industrial economies, which are in turn more competitive than other developing economies and the LDCs.

The emerging industrial economies seem much closer to the industrialized economies than to the other developing countries. The difference in proximity is partly due to China's traditional classification as an emerging industrial economy, which this report's country classification observes. But even when China is taken out of the emerging industrial economies group, most of the difference remains, suggesting a systemic difference in industrial competitiveness between the emerging industrial economies and the other developing economies. While most emerging industrial economies are in the upper middle quintile of competitiveness and some (China, Mexico, Thailand and Turkey) compete with industrialized economies for positions in the top quintile, the other developing economies are distributed around the lower middle quintile and none reaches into the top quintile.

Sustainable Development Goal 9

SDG 9 aims to "build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation." SDG 9 includes eight targets, and 13 indicators to measure those targets. Among the targets, six link directly to UNIDO's mandate as they cover the economic, social and environmental dimensions of ISID. Three of the indicators are part of the construction of the CIP Index.

SDG 9.2.1 Manufacturing value added as a proportion of GDP and MVA per capita

The level of industrialization is central to SDG 9. It is often measured as MVA per capita and as the share of MVA in gross domestic product (GDP). Taken together, these indicators reflect countries' manufacturing capabilities. SDG target 9.2 aims to "significantly

“Micro, small and medium-sized enterprises are the major sources of employment in developing economies

increase” the level of industrialization in developing countries. The target for LDCs is even more ambitious, to double the share of manufacturing in GDP.

The capacity to produce manufactured goods is also a key aspect of industrial competitiveness, and so MVA per capita is included in the first dimension of the CIP Index and MVA as a share of GDP in the second dimensions (see Annex B.2).

SDG 9.2.2 Manufacturing employment as a proportion of total employment

Manufacturing employment as a share of total employment is a good indicator of structural change in an economy as a country moves from labour-intensive production to capital-intensive production.[3] It also reflects the share of the population that directly benefits from the country’s industrial sector.

This indicator is not included in the CIP Index for reasons that go beyond data availability in developing countries. Manufacturing employment as a proportion of total employment provides an ambiguous signal regarding the industrial competitiveness of an economy. An increase might look positive because it indicates that a higher share of people is benefitting from the industrial sector. But it might also indicate that the economy is specializing in labour-intensive sectors—featuring low salaries for low-priced and unskilled labour and limited creation of valued added —and thus failing to maximize long-term productive capabilities. Conversely, a reduction of manufacturing employment as a proportion of total employment might indicate that the economy is moving from labour-intensive towards knowledge-intensive sectors, adding more value to products and moving up the technological ladder while incorporating labour-saving technologies that increase industrial competitiveness.

Moving up the technological ladder—a pattern of structural change and sectoral specialization—takes place in some countries. But incorporating labour-saving technologies is global, as the world’s MVA continues to rise at the same time that manufacturing employment falls (see Chapter 5).

SDG 9.3.1 Proportion of small-scale industries in total industry value added

Micro, small and medium-sized enterprises are the major sources of employment in developing and emerging economies and therefore fundamental to providing incomes and alleviating poverty. Small-scale industries can easily participate in local markets, do not require huge investments or advanced technology and build on local know-how to respond flexibly to changing market conditions.

Yet, increasing the proportion of small-scale industries in an economy can be detrimental. They often have low productivity and offer low wages due to internal inefficiencies and an unsupportive business environment. On average, they are much less competitive than their bigger counterparts.

So, effective policies and an effective regulatory environment will support small-scale industries in accessing finance, interacting with suppliers and customers and reaching global markets. This will allow them to drive innovation in specific niches that directly benefit the population.

SDG 9.3.2 Proportion of small-scale industries with a loan or line of credit

Small-scale industries often lack access to finance to realize their potential, despite the comparatively small capital they need. The country may lack financial infrastructure. And banks are unlikely to provide credit for individuals who lack collateral, financial literacy and even bank accounts—factors that cumulatively make small-scale industries more likely to default on their debt. So, these firms often have access only to informal credit, which can be considerably more expensive than that offered in the formal banking sector.

Policies can support small-scale firms’ accessing to credit by reducing the risk of offering it. To share the risk, governments could offer financial backing to replace the collateral banks would otherwise require. And they can provide the infrastructure and skills necessary to ensure credit access to women. Credit access encourages entrepreneurship and innovation to exploit market opportunities. It can thus increase

Sustainable industrialization requires global cooperation and integration

small-scale firms' competitiveness and enable them to integrate into local and global value chains.

SDG 9.4.1 Carbon dioxide emissions per unit of value added

Around one-third of global carbon dioxide (CO_2) emissions are attributed to the manufacturing sector. Industrial development must, therefore, adapt to integrate environmental targets by adopting more efficient technologies and upgrading infrastructure to limit greenhouse gas emissions. SDG 9.4.1 highlights the need to reduce emission intensity, measured as CO_2 emissions per unit of MVA.

Preservation of natural systems is imperative for every country's welfare and must therefore be integrated into any development strategy. For this reason, the 2018 edition of the CIP report tried to incorporate environmental damage from industrial production with an adjusted CIP Index, in which the adoption of the most efficient technologies, the production of less emissions-intensive goods and investments in pollution abatement positively affect a country's evaluated level of competitiveness.

Preserving the environment goes beyond the impact of any single country's environmental actions on its industrial competitiveness. It requires cooperation every country should contribute to, since its success (or failure) will have a global impact—so, sustainable industrialization requires global cooperation and integration. Global policies supporting environmentally sustainable manufacturing should promote economic growth and social inclusion, but not at environmental cost (UNIDO 2019b).

SDG 9.b.1 Proportion of medium- and high-tech industry value added in total value added

SDG 9.b.1 assesses the technological deepening of a country's industrial sector based on the share of medium- and high-technology industry value added in total value added. This indicator is captured in the second dimension of the CIP Index (see Annex B.2—the indicator is calculated from the table's first and third columns).

This indicator is key to evaluating competitiveness as reflected in a country's capability to innovate and absorb new technologies, which is pivotal to long-term economic development and welfare. The share of medium- and high-technology industry in total production is highly correlated with levels of productivity and value added. That kind of industry is often linked with creating products with high knowledge content, which further increases the potential for knowledge spillovers across industries, thus increasing the productivity of the entire economy.

Notes

1. More detailed results of the CIP Index can be found in the Competitive Industrial Performance Report 2018 (UNIDO 2019b).
2. The distance between Europe and the other economy groups is considerable, but it also varies across dimensions. This existing heterogeneity in the CIP dimensions seems to fall short when comparing it with the existing differences of economies in the same region. For instance, without Bermuda, North America will be placed in the first position of the economy groups ranking, as United States and Canada jointly present a higher level of industrial competitiveness than their European counterparts.
3. The direction of the structural change moving from or towards capital-intensive modes of production depends on a country's trade openness and comparative advantages. Openness to trade and participation in global value chains lead to specialized production of specific goods that a country has a comparative advantage in. This stimulates competitiveness and increases net welfare. But the effects are not homogeneous across countries or across the labour force. Countries specializing in labour-intensive goods are expected to present higher employment rates in manufacturing than countries specializing in capital-intensive goods. And the sectoral specialization is not the only influence on employment. Foreign competition forces workers in uncompetitive industries to relocate to high-productivity sectors. Their ability to do so depends on whether they have the specific skills needed for a different sector or can acquire them. So, there may be losers, even in highly competitive economies.

Annexes

Annex A.1

Producing the landscape of production and use of ADP technologies (Chapter 1)

The landscape presented in Chapter 1 is based on a combination of two sources that provide reliable and comparable data for all economies of the world: patent and trade data. Patent data are used to evaluate the innovativeness of economies in advanced digital production (ADP) technologies. Export data are used to analyse the competitiveness of economies producing capital goods related to these technologies, while import data are used to analyse the degree to which economies are using the technologies. This appendix explains the details of the procedures used to identify the relevant universe of patents and tradable goods (Section 1) and the criteria used to identify different groups of economies based on these variables (Section 2).

Measuring the creation and diffusion of ADP technologies using patent and trade data

The goal is to capture in the same characterization the creation and diffusion of the core ADP technologies described in Chapter 1. Creation entails the invention of these technologies, while diffusion refers to their use in production. For countries that are not creating the technologies, their use is typically confined to the purchase of capital goods that embody them (such as industrial robots and 3D printers). Creation can thus take two forms: the invention of the technology and the production of capital goods embodying it. Patent data can capture the former, while trade data can capture the latter. Exports of these goods would indicate production capabilities, while imports of them would indicate a certain degree of using them.

Keeping this goal in mind, Foster-McGregor et al. (2019) put forward a methodology to identify ADP patents and internationally traded goods. The focus is on four technologies: computer-aided design and computer-aided manufacturing (CAD-CAM), robotics, machine learning and additive manufacturing. As a first step, they identify patents that can be associated with those technologies, building on the classification scheme provided by the Derwent Innovation Index of Clarivate Analytics. For the first three technologies they focus on the class code T06, "Process and Machine Control," extracting only patents within this code that are also related to either digital data exchange or machine learning, and applied to manufacturing production. For additive manufacturing, they focus instead on the international patent classification code B33Y, which specifically identifies 3D printing–related inventions. Their analysis identifies a total of about 45,000 patent family applications related to these fields. From this total, about 7,000 are regarded as high-quality/value patents or "global patents," since they were simultaneously filed in at least two of the four major patent offices in this technology field: the European Patent Office, the United States Patent and Trademark Office, the Japan Patent Office and the China National Intellectual Property Administration Office. The remaining 38,000 patent families are generically labelled as "regular patents."

The second step of their analysis looks into trade statistics and identifies goods that can be associated with three technologies: CAD-CAM, robotics and additive manufacturing. The other key ADP technologies (such as big data, cloud computing and machine learning) are not considered since software is the most important part of these technologies and is hard to find in the trade classification. Table A1.1 below presents the Harmonized System (HS) codes included in the analysis to identify the closest goods that can be associated with the three technologies covered.

A warning: the imperfect overlap between these technologies and the HS codes inevitably means that earlier vintages of technology (such as third industrial revolution technologies) are included in the classification. Despite this, the data should provide good insights into the production and use of advanced technologies in these domains and identify countries with the capabilities to use (and potentially benefit) from such technologies.

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Table A1.1
Identifying ADP-related capital goods in trade statistics

Technology	Harmonized System codes included
Additive manufacturing	847710 (Injection-moulding machines) 847720 (Extruders) 847730 (Blow moulding machines) 847740 (Vacuum moulding machines and other thermoforming machines) 847751 (Other machinery for moulding or otherwise forming: For moulding or retreading pneumatic tires or for moulding or otherwise forming inner tubes) 847759 (Other machinery for moulding or otherwise forming) and 847790 (Parts)
CAD-CAM	845811 (Horizontal lathes: Numerically controlled) 845819 (Other lathes: Numerically controlled) 845921 (Other drilling machines: Numerically controlled) 845931 (Other boring-milling machines: Numerically controlled) 845951 (Milling machines, knee-type: Numerically controlled) 845961 (Other milling machines: Numerically controlled) 846011 (Flat-surface grinding machines, in which the positioning in any one axis can be set up to an accuracy of at least 0.01 mm: Numerically controlled) 846021 (Other grinding machines, in which the positioning in any one axis can be set up to an accuracy of at least 0.01 mm: Numerically controlled) 846031 (Sharpening (tool or cutter grinding) machines: Numerically controlled) 846221 (Bending, folding, straightening or flattening machines (including presses): Numerically controlled) 846231 (Shearing machines (including presses), other than combined punching and shearing machines: Numerically controlled) 846241 (Punching or notching machines (including presses), including combined punching and shearing machines: Numerically controlled)
Robotics	847950 (Industrial robots, not elsewhere specified or included)

Source: Foster-McGregor et al. 2019.

Constructing the groups of economies

The characterization in Chapter 1 distinguished four broad groups of economies (frontrunners, followers, latecomers and laggards) and, within two of them, producers and users. The final result are the six groups in Chapter 1.

Frontrunners are economies with above-average numbers of global patent family applications.[1] Due to the high concentration in the distribution of this type of patent, only 10 economies show above-average values. They also present above-average market shares in the export and import of goods associated with ADP technologies.

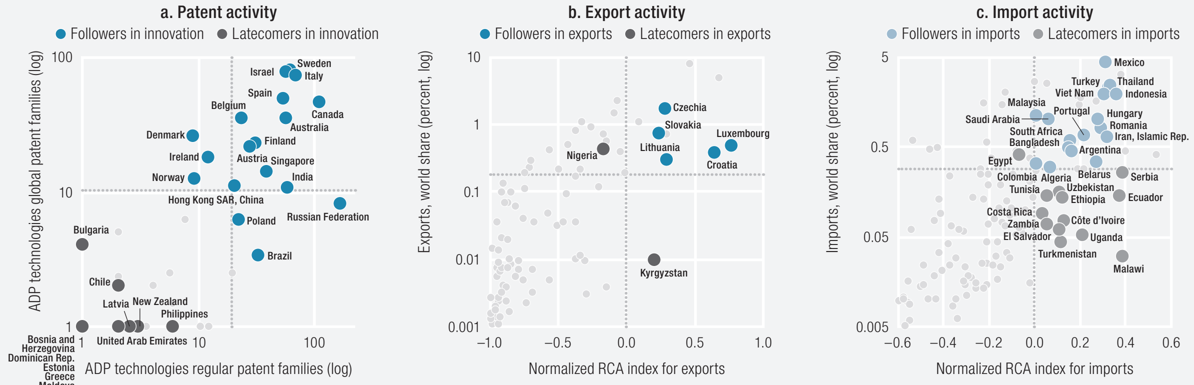
All other categories are defined by looking simultaneously at the distributions of six variables: applications by patent family (considering both regular[2] and global families), world market shares in trade (both exports and imports) and revealed comparative advantages in trade (for exports and imports). For each variable, countries are compared with the world average after frontrunners are excluded from the analysis.

For innovation, we consider as followers all economies that show an above-average number of applications of global or of regular patent families. After the frontrunners are excluded, these average values are 10 and 20, respectively. Countries below the average but still having non-zero patent activity are considered latecomers as innovators.

For export and import activity, we consider as followers economies that not only present above-average market shares but also a relative specialization in the trade of these capital goods (a revealed comparative advantage above 1). The corresponding world market average shares are 0.18 percent for exports and 0.29 percent for imports. Latecomers, in turn, are economies that present either above-average market shares or relative specialization in the trade of these goods, but not both simultaneously.

All other economies are laggards. Figure A1.1 presents the results of this characterization. Each panel shows the economies with some activity in the corresponding dimension (patents, exports or imports) that have not been categorized as frontrunners. They also present the average values of each dimension and identify the economies that fall in each of the six groups.

Figure A1.1
Characterization of economies: followers and latecomers



Note: ADP is advanced digital production. RCA is revealed comparative advantage. A positive normalized RCA index indicates relative specialization in exporting (importing) ADP goods. Frontrunners are excluded from the figure. The dashed lines show the average value of the corresponding indicator. Panel a includes 50 economies with at least one patent family in this technology field. Panel b includes 160 economies with non-zero values in exports of these goods. Panel c includes 167 economies with non-zero values in the imports of these goods. Economies are included in the maximum category to which they belong.

Source: UNIDO elaboration based on dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018) and BACI International Trade Database (Gaulier and Zignago 2010).

Table A1.2
Countries and economies by level of engagement with ADP technologies applied to manufacturing

	Followers (40 economies)		Latecomers (29 economies)		
Frontrunners (10 economies)	As producers (23 economies)	As users (17 economies)	As producers (16 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).

Annex A.2

Knowledge-intensive business services and robots (Chapter 2)

Measuring knowledge-intensive business services

Growing intersectoral linkages between manufacturing and services have contributed to the "blurring of traditional sectoral boundaries" (Berardino and Onesti 2018) in which the role of each sector in the production of goods is increasingly difficult to disentangle. Measuring how services, particularly knowledge-intensive ones, contribute to the production of manufactured goods is not easy. It requires the use of specific indicators capable of isolating their contribution. An approach used extensively in the literature relies on the use of input–output-based measures to identify and quantify the intersectoral linkages between manufacturing and services.

That strategy is based on the subsystem approach. Building on the seminal contributions of Sraffa (1960) and Pasinetti (1973), the subsystem approach seeks to divide the economy into independent, vertically integrated production systems with no exchanges among each other. A subsystem is an autonomous part of the economy that includes all factors that directly and indirectly contribute to satisfying the final demand in manufacturing or services. Each subsystem represents all the domestic activities to satisfy the final demand for a particular product (Ciriaci and Palma 2016, Montresor and Marzetti 2011).

The contribution of a given knowledge-intensive business service (KIBS) industry to the final output of one specific subsystem (for instance, the manufacturing subsystem) can then be measured as its share in the total value added generated by the subsystem. This vertical representation of a subsystem contrasts with the horizontal representation of the production structure, typically used in national account statistics, for instance by measuring the relative size of a sector by its share in GDP or aggregate employment, regardless of the intersectoral linkages that connect different production systems.

The difference between the horizontal and vertical representations of a sector can be illustrated by the employment figures in manufacturing and services. Take employees in business service activities that support the research and development (R&D) activity of manufacturers of electronic equipment. Although these workers are formally employed in a service sector, their labour input supports the electronic equipment industry and is ultimately embodied in the production of final manufactured goods. In a subsystem approach, these workers are computed as part of the electronic equipment subsystems.

Based on this logic, the methodology to estimate the contribution of KIBS to manufacturing simply makes use of multiregional input–output techniques to estimate the final contribution of this sector to the total value added generated by the production of final manufactured goods in one specific country. The use of multiregional input–output tables also allows for capturing the portion of KIBS outsourced from abroad.[3]

Data for the assessment of the employment impact of industrial robots

The econometric model to estimate the impact of the increased stock of industrial robots on employment draws on two major data sources: the 2016 version of the World Input-Output Database (WIOD, Timmer et al. 2015)[4] and the database on industrial multipurpose robots from the International Federation of Robotics (IFR 2017).[5]

WIOD covers 43 economies and the rest of the world with a detailed industry structure comprising 56 industries.[6] The period covered is 2000–2014. The IFR industrial robots database provides data on industrial robots by industry for all major economies. The term industrial robot follows the definition of the International Organization for Standardization: an "automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axes" (IFR 2018, p. 29). The two key variables reported in the database are the number of robots newly installed in a year and the operational stock of robots—the number of robots currently deployed (IFR 2018, p. 28). The econometric model uses the second variable.[7]

Annex A.3

Surveys of the adoption of digital production technologies by industrial firms (Chapter 3)

In 2017, a firm-level survey among Brazilian manufacturing firms identified their current and expected technological level through detailed questions about the technologies the firm employed in different business function. Following the Brazilian data collection exercise, a similar survey was conducted in Argentina in 2018. To expand the coverage of these surveys and provide a more global picture, UNIDO promoted similar firm-level surveys in Ghana, Thailand and Viet Nam in 2019.

Differences and similarities across the surveys are present in the sample composition—that is, sectoral coverage, size of interviewed firms, and final sample size (Table A3.1 and Table A3.2). The UNIDO survey questionnaire also presents some differences from the questionnaires used in Argentina and Brazil (Table A3.3).[8]

Sample and coverage

The Brazilian survey was an initiative of the Brazilian National Confederation of Industry (CNI) implemented by the Euvaldo Lodi Institute (IEL) and technically executed by the Federal University of Rio de Janeiro and State University of Campinas (Unicamp). Conducted between May and October 2017, it covered 711 firms (Table 3.6) that had a minimum of 100 employees operating in the following sectors: agroindustry (food products, beverages and tobacco), automobile (motor vehicles and auto parts), basic metals (iron, steel, pulp, cement), capital goods (electrical machinery, machinery and equipment), chemicals (petrochemicals, rubber and plastic products), consumer goods (textiles, garments, footwear, durable goods) and information and communications technology (office and computing machinery, communication instruments) and other sectors. The sample was stratified by sector and size.

The Argentine survey was an initiative of the Institute for the Integration of Latin America and the Caribbean (INTAL-IADB) in cooperation with the Center for the Implementation of Public Policies Promoting Equity and Growth (CIPPEC) and the Argentinean Industrial Union (UIA). Conducted in the second half of 2018, it covered 293 firms operating in six sectors of manufacturing industry: processed foods products, steel, light vehicles and parts and accessories, textile, agricultural machinery and biopharmaceuticals. The sample was stratified by sector and size.

The Ghanaian survey, a UNIDO initiative, was conducted in the first half of 2019 in collaboration with the Council for Scientific and Industrial Research (CSIR)-Science and Technology Policy Research Institute (STEPRI). The targeted sample was 200 firms in the main economic areas of the country, in the regions of Greater Accra and Ashanti. The targeted firms were operating in five selected industrial activities (see Table A3.1). The sample was stratified by region, sector and size.[9]

The Thai survey, a UNIDO initiative, was conducted in the first half of 2019 with the financial and technical support of the Digital Economy Promotion Agency, Ministry of Digital Economy and Society. The targeted sample was 200 firms located in the Eastern Economic Corridor. The targeted firms were operating in four selected industrial activities (see Table A3.1). The sample was stratified by region, sector and size.[10]

The Vietnamese survey, a UNIDO initiative, was conducted in the first half of 2019 in collaboration with the National Center for Economic Forecast and Information. The targeted sample was 250 firms in the main economic areas of the country, the regions around Hanoi and Ho Chi Minh City. The targeted firms were operating in four selected industrial activities (see Table A3.1). The sample was stratified by region, sector and size.

The methodology known as proportional probabilistic sampling was used to identify the sample frame. Once the sample frame was defined, firms were chosen randomly from data banks on industrial firms in each country (such as business registries). The questionnaire was answered either by telephone followed

Table A3.1
Country samples and industry coverage

		Argentina	Brazil	Ghana	Thailand	Viet Nam
Sample size		297	711	197	200	261
Sectors						
Food and beverages		●	●	●	●	●
Textile and apparel		●	●	●	●	●
Electronics			●		●	●
Automotive		●	●		●	●
Metals				●		
Plastic and rubber				●		
Wood and furniture				●		
Firm size (number of employees)						
Minimum firm size		—	100	20	20	20
Types of firms included	0–19	●				
	20–49	●		●	●	●
	50–99	●		●	●	●
	100+	●	●	●	●	●

Source: UNIDO elaboration based on data collected by the UNIDO firm-level surveys "Adoption of digital production technologies by industrial firms" and on Albrieu et al. (2019) and Kupfer et al. (2019).

by internet data collection (in Argentina and Brazil) or in face-to-face interviews by trained enumerators (in Ghana, Thailand and Viet Nam).

Since each country survey has unique sector and size specifications, some methodological steps were taken to build a dataset with comparable data that would allow for intercountry analysis. Firms from each original country database were organized according to common sectoral and size classifications. Then, after the identification of incongruences and the standardization of samples by country, the information was filtered to maintain respondents only in common sectors of activities. A final database of 1,157 firms was obtained (Table A3.2).

For covered topics (Table A3.3), the Brazilian survey focused mostly on the current and expected use of digital production technologies, with a set of detailed and specific questions about digital technology generations. All surveys included the same set of questions on digital technologies, which represent the core of the survey as well as the main "common denominator" across surveys. The Argentine survey extended the original scope of the Brazilian survey to include the possible implications for employment levels and skills. The UNIDO surveys in Ghana, Thailand and Viet Nam involved an even more complete set of topics, such as location of production and energy and sustainability. The UNIDO surveys also collected general firm characteristics (such as revenues from sales, number of employees and type of employees).

Two dimensions of heterogeneity: Technological generations and business functions

To adequately account for heterogeneity and for the coexistence of different production technologies, the

Table A3.2
Final sample composition by firm size and industry

Country	Size	Sector: TDI industries	Sector: Other sectors	Total
Argentina	Large	22	16	38
	Small	58	75	133
	Total	80	91	171
Brazil	Large	193	135	328
	Small	—	—	—
	Total	193	135	328
Ghana	Large	—	59	59
	Small	—	138	138
	Total	—	197	197
Thailand	Large	69	36	105
	Small	45	50	95
	Total	114	86	200
Viet Nam	Large	73	84	157
	Small	49	55	104
	Total	122	139	261
Total		509	649	1,157

Note: Large firms have 100 or more employees. Small firms have fewer than 100 employees. TDI is technology- and digital-intensive. TDI industries include automotive and auto parts and electronics. Other sectors include food and beverages; textiles, leather and footwear; plastic and rubber; metal products; wood products; and furniture.
Source: UNIDO elaboration based on data collected by the UNIDO firm-level surveys "Adoption of digital production technologies by industrial firms" and on Kupfer et al. (2019).

Table A3.3
Topic coverage by individual country

Topics	Argentina	Brazil	Ghana	Thailand	Viet Nam
Current and expected use of digital production technologies	●	●	●	●	●
Employment and skills	●		●	●	●
Location of production and trade			●	●	●
Energy and sustainability			●	●	●

Source: UNIDO elaboration based on data collected by the UNIDO firm-level surveys "Adoption of digital production technologies by industrial firms."

surveys in all five countries used a common methodology, grounded on two specifications. The first specification regards the coexistence of various generations of digital technologies within the same productive structures. All surveys followed a framework based on different digital technological generations, going from simple and analog ones (generation 0.0) to the most cutting-edge advanced digital production technologies (generation 4.0), as defined in Chapter 1 (see Figure 1.20). The second specification is related to the coexistence of different production technologies across different organizational functions even within the same firm. Five business functions were thus specified: supplier relations, product development, production management, customer relations and business management.

By putting together these two specifications, a stylization of different generations of digital technologies by business functions was obtained (Table A3.4). This implies that, when asked about the most used technological generation, firms were not given a binary option (such as adopting or not adopting a specific advanced digital technology) but, instead, different alternatives ordered according to the degree of digital sophistication, each specifying different technical solutions.

Measures for adoption of technological generations and readiness

The information on the technological generations adopted in each business functions can be used to assign a level of digital development to each firm. Although the availability of various answers (current and expected generations, and actions in five business functions) can provide a more consistent result than having to rely on only one observation, the disaggregation in different business functions poses a methodological challenge: how to assign to each firm a unique value representing its (current and expected) technological level, as well as the nature of mobilization efforts currently being executed? For this purpose, three firm-unique indicators were developed: currently adopted technological generation ($Firm_c$); technological generation expected to be adopted in 5 to 10 years ($Firm_e$); and the stage of execution of plans and actions to reach the projected generation ($Firm_a$). These three aggregate indexes serve as the basis for

Table A3.4
Digital technology generations and business functions

Generation of digital technologies		Business function: Supplier relationship	Business function: Product development	Business function: Production management	Business function: Client relationship	Business function: Business management
G 4.0	Fourth generation: smart production	Real time web-based relation	Virtual development systems (such as virtual manufacturing)	Machine-to-machine system, cobots, augmented reality, additive manufacturing	Client relationship based online monitoring product use (such as artificial intelligence in customer services)	Business management supported by big data analytics
G 3.0	Third generation: integrated production	Digital system for processing orders, stocks and payments	Integrated data product system (such as product data management and/or product lifecycle management)	Computerized process execution system	Internet based support for sales and after services (such as mobile app, customer data analytics)	Integrated platform to support decision making (such as advanced enterprise resource planning)
G 2.0	Second generation: lean production	Automated electronic transmission of orders (such as email)	Computer-aided design and computer-integrated manufacturing, computer-aided engineering, computer-aided process planning	Partially or fully integrated computer-aided manufacturing	Automated devices to support sales (such as customer relationship management)	Enterprise resource management in few areas (such as enterprise resource planning)
G 1.0	First generation: rigid production	Manual electronic transmission of orders (such as email)	Stand-alone computer aided design	Stand-alone automation	Electronic contact (such as spreadsheet registry, email)	Information systems by area/department
G 0.0	Zero generation: analog production	Manual transmission of orders (such as personal contact, telephone)	Manual generation of designs (such as 2D/3D drawings in 2D space)	Non-micro-electronic based machinery	Manual handling of contacts (such as personal contact, telephone)	No software support to business management

Note: The technical solutions identified in correspondence of each technological generation and each business function have been specified with the support of specialized engineers (IEL 2018). Generation 0.0 was included only in the survey questionnaires collected in Ghana, Thailand and Viet Nam.
Source: UNIDO elaboration based on Indústria 2027 Survey (IEL 2018) and on Kupfer et al. (2019).

development of a fourth indicator: the UNIDO Digitalization Readiness Index (DRI).[11]

Currently adopted ($Firm_c$) and expected ($Firm_e$) technological generation

First, for each of the five business functions f_i, the firm indicates the current and expected technological generation. Depending on its answers, for each business function the firm is assigned a score between 0 (for generation 0.0) to 4 (for generation 4.0) for current and expected technological generation. Second, the smallest value of f_i is disregarded, assuming that even a technologically advanced firm may not need to adopt the most advanced technologies in all five business functions (for instance, firms operating on a subcontracting basis may not need an integrated and fully automated customer relationship). Third, for each firm an aggregate score—Sum_c (for current technology generation) or Sum_e (for expected)—is obtained by summing up the scores of the four remaining f_i (same procedure for Sum_e):

$$(1)\ Sum_c = \sum_{i=1}^{4} f_i\_c - \min\{f_i\_c\},\ where\ 4 \le Sum_c \le 16$$

Fourth, to proxy for the technological generation associated to the firm, an aggregate index ($Firm_c$ or $Firm_e = 0,1,2,3,4$) is identified according to where the firm's score falls within a range of limit values defined as follows (same procedure for $Firm_e$):

$$(2)\ Firm_c = \begin{cases} 0 = generation\ 0.0\ if\ 0 \le Sum_c < 4 \\ 1 = generation\ 1.0\ if\ 4 \le Sum_c \le 6 \\ 2 = generation\ 2.0\ if\ 7 \le Sum_c \le 9 \\ 3 = generation\ 3.0\ if\ 10 \le Sum_c \le 12 \\ 4 = generation\ 4.0\ if\ 0 \le Sum_c \le 16 \end{cases}$$

The results in Chapter 3 correspond to the number of firms falling in each category as a share of the total number of firms in the considered sample.

Plans and actions to reach the projected generation ($Firm_a$)

A similar four-step procedure was applied for the aggregate mobilization effort index ($Firm_a$). For each business function f_i, the firm indicates whether it is already taking actions to reach the future technological generation, choosing among four possible types of actions—no action, ongoing initial studies, plan already formalized but not yet implemented, and plan formalized and already in execution. Depending on its answers, the firm is assigned a score between 1 (for no actions) and 4 (for plans in execution). Once the smallest value has been disregarded, each firm obtains an aggregate score (Sum_a) depending on the sum of the scores in the four remaining f_i. The aggregate index ($Firm_a$ = 1,2,3,4) to proxy for each firm's efforts is identified according to where the firm's score falls within a range of limit values:

$$(3)\ Firm_a = \begin{cases} 1 = \textit{no action if } 4 \le Sum_a \le 6 \\ 2 = \textit{initial studies if } 7 \le Sum_a \le 9 \\ 3 = \textit{plan available but not yet implemented if } 10 \le Sum_a \le 12 \\ 4 = \textit{plan in execution if } 13 \le Sum_a \le 16 \end{cases}$$

UNIDO digitalization readiness index

The UNIDO Digitalization Readiness Index (DRI) is meant to proxy the readiness of the firm to adopt more advanced production technologies. It is obtained combining the three aggregate indices—$Firm_c$, $Firm_e$ and $Firm_a$—in such a way that the expectations about future technology generation are "grounded" using the information about the type of actions the firm is currently undertaking, these being an indication of the likelihood of reaching the expected technology generation.

The DRI is obtained as:

$$(4)\ DRI = Firm_c + (Firm_e - Firm_c) * \alpha$$

where α is a parameter whose value is defined as:

$$(5)\ \alpha = \begin{cases} 0 & \textit{if } Firm_a = 1\ (\textit{no action}) \\ 0.33 & \textit{if } Firm_a = 2\ (\textit{initial studies}) \\ 0.66 & \textit{if } Firm_a = 3\ (\textit{plan available but not yet implemented}) \\ 1 & \textit{if } Firm_a = 1\ (\textit{plan in execution}) \end{cases}$$

Based on their DRI, firms are classified in three readiness categories, as follows:

$$(6)\ \textit{Firm readiness category} = \begin{cases} 1 = \textit{lagging behind if } \text{DRI} \le 2 \\ 2 = \textit{catching up if } 2 < \text{DRI} < 4 \\ 3 = \textit{forging ahead if } 4 \le \text{DRI} \end{cases}$$

Table A3.5 summarizes the results and the relationship between the three aggregate indices—$Firm_c$, $Firm_e$ and $Firm_a$—and the readiness categories.

Table A3.5
Firm readiness categories

		$Firm_a$			
$Firm_c$	$Firm_e$	1	2	3	4
0 or 1	0 or 1	1	1	1	1
	2	1	1	1	1
	3	1	1	2	2
	4	1	1	2	2
2	2	1	1	1	1
	3	1	1	2	2
	4	1	1	2	3
3	3	2	2	2	2
	4	2	2	3	3
4	4	3	3	3	3

Note: A firm is not allowed to advance three generations even if there are plans in execution (for example, a firm that is currently in generation 1.0 and is expecting to be in generation 4.0 in 5 to 10 years). In this case, the firm is assigned $Firm_e = Firm_c$. A firm is excluded if the expected technology generation in future is lower than current one.
Source: Kupfer et al. 2019.

Annex A.4

Summary of strategic responses to ADP technologies in 11 countries (Chapter 4)

Table A4.1
Strategic responses to ADP technologies in selected economies, by geographical region

	Strategy name	Timeline	Responsible agency	Strategic objectives	Strategic sectors	Policy instruments	Performance indicators
Latin America and the Caribbean							
Argentina	Working group/ mechanism set up to develop a strategy	N/A	Ministry of Science, Technology and Productive Innovation, National Institute of Industrial Technology	N/A	Diagnostic studies ongoing or to be carried out in: • Biotechnology • Franchising • Software • Electric vehicles • Textiles • Health technologies • Computers • Aeronautics and aerospace • Shoes • Robotics • 3D printing	N/A	N/A
Brazil	Plano de CT&I para Manufatura Avançada no Brasil	N/A	Ministry of Science, Technology, Innovation and Communication	Provide Brazilian firms with conditions to access and adopt smart manufacturing ecosystems, with support from science, technology and innovation. Ultimately, this should assist the development of strategic value chains, and promising economic sectors capable of addressing local demands.	• Aerospace and defence • Agriculture • Health-related industries • Basic chemicals • Biodiversity-based industries • Digital industries • Petroleum and gas • Renewable energies	From Innovation Law (Law no. 13.243 / 2016), several possible instruments are considered: • Direct subsidies • Direct capital injection/strategic partnerships • Technology vouchers • Strategic procurement, notably of specific technologies • Tax breaks • Grants and scholarships • Investment funds • Financial securities, either encouraged or not • Investment in research and development within public service concessions or sectoral contracts	Document provides substantive evidence of scientific and technological production in Brazil and of technological adoption by firms.

Table A4.1 *(continued)*

Strategic responses to ADP technologies in selected economies, by geographical region

	Strategy name	Timeline	Responsible agency	Strategic objectives	Strategic sectors	Policy instruments	Performance indicators
Chile	Strategic Programme Smart Industries (PEII) 2015–2025	2015–2017 (short-term), 2018–2020 (medium-term) and 2020–2025 (long-term)	Chilean Economic Development Agency (CORFO)	• Develop an enabling digital ecosystem to underpin industrial transformation • Facilitate coordination between industrial supply and demand • Develop a mechanism to identify and select priority sectors • Contribute to productivity and value addition in domestic industry	• Mining (particularly copper) • Agriculture and food • Smart cities • Other sectors to be identified in the future	Public–private partnerships	• Increased available speed for national broadband • Penetration of high-speed internet • Reduced deficit of human resources in ICTs • Private sector participation in PEII implementation • Number of industries involved in the programme • Interoperability in mining • Interoperability and introduction of sensor technologies in agriculture • Urban areas with smart city–enabling infrastructure
Mexico	Roadmap	2030	Ministry of Economy	• Increase the value content of Mexican manufactured exports • Enhance industry–academia collaboration as the basis for innovation • Become a dynamic market for IoT within a decade of adoption of the roadmap	Automotive, aerospace and chemicals as case studies of the country's manufacturing paradigms. Other sectors will be designed based on findings from other thematic roadmaps	• Pilot programmes • Boost digitization and access to internet services in the country	• In 2019 and 2021, two regional clusters should be set in place with a mandate to develop Industry 4.0 hyper-flexible manufacturing operating systems, which will be the platform for systems integration and application development • By 2022, the value of the domestic market for IoT should amount to about $8 billion

Table A4.1 *(continued)*

Strategic responses to ADP technologies in selected economies, by geographical region

	Strategy name	Timeline	Responsible agency	Strategic objectives	Strategic sectors	Policy instruments	Performance indicators
Asia and Pacific							
China	Made in China 2025	2025, with milestones for 2020	Ministry of Industry and Information Technology (MIIT) is the lead agency, but responsibilities for implementation are shared by other agencies at different levels	To facilitate the country's evolution from a large manufacturing country to a "manufacturing power" strong in innovation and manufacturing	• High-grade computer numerical control machine tools and robots • Aerospace equipment, marine engineering equipment, high-tech ships • Advanced rail transit equipment • Energy-saving and new energy vehicles • Electric power equipment • Agricultural machinery and equipment • New material • Biomedicine and high performance medical devices	• Public–private partnership • Value added tax reform to take R&D into deduction • Perfecting the multi-level talent training system	• R&D/revenue • Patents/revenue • Competitiveness Index* • Value added ratio increase • Labour productivity growth rate • Broadband penetration rate • Digital R&D and design tools penetration rate • Computer numerical control of key processes • Reduction in energy consumption per MVA • Reduction in CO_2 emission per MVA • Reduction in water consumption per MVA • Industrial solid waste comprehensive use rate
Malaysia	Industry4wrd	2025	Ministry of International Trade and Investment	• Attract stakeholders to smart manufacturing technologies and processes. Increase Malaysia's attractiveness as a preferred manufacturing location • Create the right ecosystem for smart manufacturing in line with existing and future development initiatives • Transform domestic industry capabilities	• Electrical and electronics • Machinery and equipment • Chemicals, aerospace and medical devices • Automotive • Textiles • Transport • Pharmaceuticals • Metal • Food processing • Services	• Funding and outcome-based incentives (tax incentives) • Enabling ecosystem and digital infrastructure (digital connectivity between different stakeholders, notably government, firms and education organizations) • Regulatory frameworks (creating a dedicated smart manufacturing platform, several issues around data generation, storage and use) • Dedicated training and upskilling programmes • Access to smart technologies and standards (through public–private partnerships)	• Increase by 30 percent productivity per person, from about $25,000 • Increase the absolute contribution of manufacturing to the national economy from about $60.7 billion to $93.7 billion • Climb from 35th place to the top 30 in the Global Innovation Index ranking • Augment from 18 percent to 35 percent the share of high-skilled workers in manufacturing

Table A4.1 *(continued)*
Strategic responses to ADP technologies in selected economies, by geographical region

	Strategy name	Timeline	Responsible agency	Strategic objectives	Strategic sectors	Policy instruments	Performance indicators
Thailand	Thailand 4.0 20-Year National Strategy (2017–2036) 12th National Economic and Social Development Plan (2017–2021)	2017–2036	Ministry of Industry	• Help Thailand overcome middle-income trap • Reduce disparities and imbalanced development • Promote a science, technology and innovation–driven economy	• Five existing and five emerging strategic sectors to be identified	• Digital parks, development zones • Learning centres • International collaboration mechanisms • Investment in high-speed internet infrastructure • Institutional reforms to create framework conditions for development of key sectors, including specific incentives (corporate tax reductions, R&D subsidies)	• To be determined
Viet Nam	Directions on formulating the national industrial development policy until 2030 with a vision towards 2045	2025 with milestones for 2020	Ministry of Science and Technology (MOST) is the lead agency, but responsibilities were distributed across different agencies at different government levels	• Strengthening the country's capacity to address smart production	• Broadly defined as ICTs, education, science and technology, but also sectors in fiscal and foreign trade	• To be determined	• To be determined
Africa							
South Africa	Industrial Policy Action Plan 2017/18–2019/20	Depending on initiative	Department of Trade and Industry, Department of Science and Technology	• Enhance policy coordination • Reform institutional environment to boost R&D, innovation and commercialization of domestic technologies • Enhance digitalization of the economy	• Broadly defined	• Inter-agency collaborative initiatives • Development of scenarios for development of smart manufacturing and required policy responses • Specific funding for smart manufacturing–related activities • Initiatives to promote uptake and diffusion of domestic-generated technologies	• Targets for government seed investment • Number of initiatives to protect employment

Table A4.1 *(continued)*

Strategic responses to ADP technologies in selected economies, by geographical region

	Strategy name	Timeline	Responsible agency	Strategic objectives	Strategic sectors	Policy instruments	Performance indicators
Europe							
Turkey	Smart Manufacturing Systems Technology Roadmap	N/A	Higher Council of Science & Technology, the Scientific and Technological Research Council of Turkey	To be determined	• Digitalization: emphasis on big data and cloud computing, virtualization and cyber-security • Connectivity: emphasis on IoT and sensor technologies • Future factories: additive manufacturing, advanced robotic systems and automation and control systems	• To be determined	• To be determined
Middle East							
Saudi Arabia	National Transformation Program. Delivery Plan 2018–2020 Vision 2030—Industry 4.0	2030	N/A	• Increasing competitiveness of industries within sectors of the National Industrial Development and Logistics Program • Expand existing value chains and develop new ones • Mitigate impact of reforms in energy, natural gas and labour markets • Develop environmental system for smart manufacturing technologies • Create new high-skill jobs to attract national labour force	• Chemicals and pharmaceuticals • Basic materials • Food and beverage • Textiles • Advanced industries • Basic industries/ materials	• Establishment of capacity-building centres for pilot testing, demonstrating technologies, training and capacity development	• Improvements in annual operating income of existing assets of firms endorsing smart manufacturing • Total required technological cost

* Comprehensive index consisting of 12 indicators, developed by AQSIQ, the General Administration of Quality Supervision, Inspection and Quarantine.

Note: MVA is manufacturing value added. IoT is Internet of Things. R&D is research and development. ICT is information and communications technology.

Source: UNIDO elaboration.

Notes

1. The average number of patent family application across all economies with at least one patent in ADP technologies is 102.
2. That is, patent families that are not necessarily simultaneously applied in two or more of the four patent offices used to define the global patents.
3. For details of the approach, see de Macedo and Lavopa (2017).
4. Data available at http://www.wiod.org/database/wiots16.
5. See https://ifr.org/worldrobotics.
6. The industry structure is based on the Statistical Classification of Economic Activities in the European Community (NACE) Rev. 2 industry classification and the System of National Accounts 2008 (SNA2008)/European System of National and Regional Accounts 2010 (ESA2010) methodology.
7. For details of the econometric model, see UNIDO background paper prepared by Ghodsi et al. (2019).
8. More detailed information about the sampling strategy and the structure of the questionnaire of the UNIDO surveys in Ghana, Thailand and Viet Nam are reported in the UNIDO background paper prepared by Kupfer et al. (2019).
9. To avoid an over-representation of small companies in the results, a binding constraint was introduced: no more than 50 percent of small companies in each sector.
10. As in Ghana, the number of small enterprises was limited to a maximum of 50 percent per sector in the sample.
11. For more information and details on the indicators, see the UNIDO background paper prepared by Kupfer et al. (2019).

Annex B.1

Rankings on the three dimensions of the Competitive Industrial Performance Index, by geographical regions

Table B1.1
European economies' ranking on the three dimensions of industrial competitiveness

Economy	Capacity to produce and export manufactures (1st dimension) 2015	2017	Technological deepening and upgrading (2nd dimension) 2015	2017	World impact (3rd dimension) 2015	2017	CIP rank 2015	2017
Germany	5	5	6	5	3	3	1	1
Ireland	1	1	4	3	24	24	7	6
Switzerland	2	2	13	13	18	19	6	7
Belgium	4	4	21	21	17	17	8	8
Italy	19	18	24	24	7	6	9	9
Netherlands	7	7	27	30	14	13	11	10
France	22	21	22	22	6	7	10	11
Austria	6	6	16	16	25	25	14	14
Czechia	12	11	9	7	29	27	18	15
Sweden	9	10	18	19	26	26	17	16
United Kingdom	30	30	33	34	9	9	15	17
Spain	27	26	32	33	12	11	19	19
Denmark	10	9	26	20	33	33	21	20
Poland	39	36	25	26	22	22	23	23
Slovakia	14	14	10	9	41	39	25	24
Finland	13	13	30	27	39	38	26	25
Hungary	23	22	8	10	36	36	27	26
Turkey	48	48	37	37	20	20	28	28
Russian Federation	57	58	69	66	13	14	31	31
Romania	42	41	15	15	37	37	33	32
Slovenia	16	15	19	18	59	57	35	33
Portugal	35	34	49	48	42	42	34	34
Norway	18	20	59	67	43	46	32	36
Lithuania	26	25	36	39	60	59	40	40
Luxembourg	8	8	67	69	74	75	42	44
Belarus	49	50	23	23	56	55	45	46
Estonia	25	24	39	42	71	73	49	48
Greece	50	47	71	72	53	50	52	50
Croatia	45	43	43	46	67	63	56	54
Bulgaria	54	51	51	51	62	60	58	55
Latvia	41	40	55	55	77	76	59	57
Serbia	65	62	44	44	69	69	65	62
Malta	32	28	48	41	100	98	66	64
Ukraine	92	91	56	57	54	53	69	67
Iceland	24	27	87	89	104	107	71	73
North Macedonia	61	57	35	36	93	91	79	74

Table B1.1 *(continued)*

European economies' ranking on the three dimensions of industrial competitiveness

Economy	Capacity to produce and export manufactures (1st dimension) 2015	2017	Technological deepening and upgrading (2nd dimension) 2015	2017	World impact (3rd dimension) 2015	2017	CIP rank 2015	2017
Bosnia and Herzegovina	68	64	65	65	87	87	82	80
Cyprus	74	67	66	78	123	114	95	92
Georgia	96	93	74	74	108	103	96	94
Republic of Moldova	113	111	73	70	124	123	111	106
Albania	98	100	131	132	118	117	109	109
Montenegro	97	96	111	109	138	138	124	120
Europe (average)	38	37	42	42	53	52	43	42

Source: UNIDO elaboration based on the Competitive Industrial Performance Index 2019 database (UNIDO 2019c).

Table B1.2

North American economies' ranking on the three dimensions of industrial competitiveness

Economy	Capacity to produce and export manufactures (1st dimension) 2015	2017	Technological deepening and upgrading (2nd dimension) 2015	2017	World impact (3rd dimension) 2015	2017	CIP rank 2015	2017
United States	31	31	28	31	2	2	4	5
Canada	20	19	46	47	11	12	16	18
Bermuda	99	97	80	77	149	148	139	136
North America (average)	50	49	51	52	54	54	53	53

Source: UNIDO elaboration based on the Competitive Industrial Performance Index 2019 database (UNIDO 2019c).

Table B1.3

Asia and Pacific economies' ranking on the three dimensions of industrial competitiveness

Economy	Capacity to produce and export manufactures (1st dimension) 2015	2017	Technological deepening and upgrading (2nd dimension) 2015	2017	World impact (3rd dimension) 2015	2017	CIP rank 2015	2017
Japan	17	17	7	6	4	4	2	2
China	52	52	5	8	1	1	3	3
Republic of Korea	11	12	1	1	5	5	5	4
Singapore	3	3	3	4	27	29	12	12
Taiwan Province of China	15	16	2	2	15	16	13	13
Malaysia	33	35	14	14	23	23	22	21
Thailand	46	46	12	12	21	21	24	27
Israel	21	23	29	28	38	40	29	29
Australia	34	33	91	95	28	28	30	30
Saudi Arabia	44	45	68	62	30	30	37	37

Table B1.3 *(continued)*
Asia and Pacific economies' ranking on the three dimensions of industrial competitiveness

Economy	Capacity to produce and export manufactures (1st dimension)		Technological deepening and upgrading (2nd dimension)		World impact (3rd dimension)		CIP rank	
	2015	2017	2015	2017	2015	2017	2015	2017
Indonesia	80	80	42	43	19	18	38	38
India	110	108	34	32	8	8	39	39
Philippines	81	81	11	11	31	32	43	41
United Arab Emirates	38	38	119	111	44	44	41	42
Viet Nam	79	77	31	29	32	31	46	43
New Zealand	37	37	94	92	57	56	48	47
Islamic Republic of Iran	77	75	62	60	35	34	53	49
Qatar	29	29	84	87	63	61	50	53
Bahrain	28	32	70	68	75	77	55	56
Kuwait	40	44	106	112	61	64	54	59
Kazakhstan	69	68	99	107	58	58	68	66
Oman	51	54	92	96	70	71	63	68
Bangladesh	114	113	63	58	45	43	73	72
Sri Lanka	86	86	75	76	65	62	78	77
Jordan	82	84	47	50	79	81	80	82
Pakistan	119	120	64	64	50	49	83	83
Lebanon	90	78	79	86	90	86	91	84
Brunei Darussalam	43	42	81	88	121	116	87	85
Hong Kong SAR, China	78	82	86	105	83	84	85	87
Cambodia	102	103	76	73	82	78	90	89
Myanmar	118	114	113	75	76	68	97	90
Armenia	95	89	110	104	114	110	104	99
Lao People's Dem. Rep.	111	110	101	103	107	105	105	103
Mongolia	88	95	136	142	109	112	102	107
State of Palestine	112	112	98	93	115	119	110	111
Fiji	87	88	102	94	134	131	116	114
Azerbaijan	107	116	135	133	95	102	103	115
Syrian Arab Republic	126	123	117	116	94	93	115	116
Kyrgyzstan	121	117	96	99	127	124	121	118
Papua New Guinea	122	122	141	135	119	120	123	122
Tajikistan	135	135	104	101	131	129	130	129
Nepal	141	139	114	115	126	125	132	132
Yemen	145	144	120	129	133	133	140	140
Maldives	120	119	148	147	146	144	144	142
Afghanistan	146	145	143	146	130	135	143	143
Macao SAR, China	124	129	149	149	144	145	145	145
Iraq	143	143	147	150	125	128	142	146
Tonga	131	130	138	131	150	150	150	150
Asia and Pacific (average)	81	81	80	80	74	73	76	76

Source: UNIDO elaboration based on the Competitive Industrial Performance Index 2019 database (UNIDO 2019c).

Table B1.4
Latin American and Caribbean economies' ranking on the three dimensions of industrial competitiveness

	Capacity to produce and export manufactures (1st dimension)		Technological deepening and upgrading (2nd dimension)		World impact (3rd dimension)		CIP rank	
Economy	**2015**	**2017**	**2015**	**2017**	**2015**	**2017**	**2015**	**2017**
Mexico	47	49	17	17	10	10	20	22
Brazil	70	69	53	52	16	15	36	35
Argentina	63	66	60	61	40	41	47	51
Chile	53	53	89	91	46	45	51	52
Trinidad and Tobago	36	39	45	45	80	82	57	58
Peru	76	72	93	90	51	48	61	60
Costa Rica	55	55	57	59	72	72	67	65
Bolivarian Republic of Venezuela	71	76	128	122	49	52	64	69
Colombia	89	92	78	80	52	51	70	70
El Salvador	72	71	50	49	81	79	76	75
Guatemala	83	85	54	54	68	70	75	76
Panama	56	61	97	102	78	80	74	78
Uruguay	58	60	90	98	84	85	77	79
Ecuador	93	94	126	127	73	74	89	91
Honduras	103	104	72	79	91	90	93	93
Paraguay	101	102	115	110	98	94	98	98
Plurinational State of Bolivia	106	106	140	128	89	89	99	100
Jamaica	94	98	85	84	113	115	100	101
Suriname	67	73	130	124	132	130	106	105
Barbados	73	74	58	56	137	139	108	108
Bahamas	91	90	77	71	140	140	120	119
Belize	100	99	124	108	141	141	127	125
Saint Lucia	104	101	123	118	147	146	136	134
Haiti	142	140	100	100	135	132	135	137
Latin America and the Caribbean (average)	79	80	86	84	84	84	83	83

Source: UNIDO elaboration based on the Competitive Industrial Performance Index 2019 database (UNIDO 2019c).

Table B1.5
African economies' ranking on the three dimensions of industrial competitiveness

Economy	Capacity to produce and export manufactures (1st dimension)		Technological deepening and upgrading (2nd dimension)		World impact (3rd dimension)		CIP rank	
	2015	2017	2015	2017	2015	2017	2015	2017
South Africa	64	65	52	53	34	35	44	45
Morocco	84	83	41	40	55	54	60	61
Tunisia	66	70	40	35	64	65	62	63
Egypt	105	105	61	63	48	47	72	71
Eswatini	60	59	38	38	103	101	81	81
Mauritius	59	56	83	82	105	104	88	86
Botswana	62	63	112	114	92	92	86	88
Algeria	108	109	146	144	66	66	94	95
Côte d'Ivoire	116	115	108	83	86	83	101	96
Namibia	75	79	118	121	101	106	92	97
Nigeria	115	132	116	119	47	67	84	102
Republic of Congo	109	107	129	123	112	108	114	104
Senegal	123	121	82	81	102	100	113	110
Kenya	128	128	95	106	85	88	107	112
Gabon	85	87	145	143	116	118	112	113
Cameroon	125	124	121	120	96	95	117	117
Zambia	127	125	133	130	106	109	118	121
Ghana	129	127	144	145	97	96	122	123
Zimbabwe	132	131	105	113	117	121	125	124
Madagascar	134	134	127	126	111	111	126	126
United Republic of Tanzania	133	136	132	139	88	99	119	127
Central African Republic	136	133	20	25	139	137	131	128
Uganda	138	138	122	125	110	113	128	130
Angola	130	126	150	148	99	97	133	131
Mozambique	137	137	137	140	120	122	129	133
Cabo Verde	117	118	107	85	143	143	138	135
Malawi	139	142	109	117	129	134	134	138
Rwanda	140	141	134	137	136	136	141	139
Ethiopia	149	146	139	136	122	126	148	141
Niger	147	148	88	97	128	127	137	144
Gambia	144	147	103	138	145	149	146	147
Burundi	148	149	125	134	142	142	147	148
Eritrea	150	150	142	141	148	147	149	149
Africa (average)	116	116	106	107	103	104	112	113

Source: UNIDO elaboration based on the Competitive Industrial Performance Index 2019 database (UNIDO 2019c).

Annex B.2

Sustainable Development Goals and the Competitive Industrial Performance Index

Table B2.1
Sustainable Development Goal 9 targets included in the CIP Index

Economy	Proportion of medium- and high-tech industry value added in total manufacturing value added (percent) 2017	Manufacturing value added per capita (2010 $) 2017	Manufacturing value added as a proportion of GDP (percent) 2017
Germany	61.68	10,064	21.33
Japan	56.77	10,191	21.14
China	41.45	2,254	31.27
Republic of Korea	63.01	7,548	28.62
United States	46.97	6,058	11.36
Ireland	54.32	24,077	32.18
Switzerland	64.55	14,688	19.07
Belgium	49.61	6,362	13.86
Italy	42.96	5,248	14.73
Netherlands	48.53	5,739	10.68
France	50.52	4,604	10.40
Singapore	78.16	9,437	17.63
Taiwan Province of China	69.53	4,525	21.94
Austria	45.97	8,913	18.03
Czechia	51.89	5,607	24.68
Sweden	52.09	7,766	13.44
United Kingdom	44.43	3,371	7.97
Canada	38.00	5,157	10.06
Spain	39.98	4,139	12.72
Denmark	55.34	7,733	12.47
Malaysia	44.12	2,682	23.28
Mexico	41.61	1,501	15.09
Poland	34.21	2,848	18.15
Slovakia	49.71	4,951	24.92
Finland	46.03	7,154	15.26
Hungary	56.59	3,007	19.10
Thailand	40.71	1,704	27.58
Turkey	32.21	2,460	16.47
Israel	42.40	4,098	11.43
Australia	28.20	3,833	6.05
Russian Federation	30.05	1,561	13.60
Romania	44.44	2,281	21.13
Slovenia	37.18	4,828	18.93
Portugal	25.04	2,856	12.41
Brazil	35.39	1,189	10.97
Norway	42.68	5,909	6.51

Table B2.1 *(continued)*
Sustainable Development Goal 9 targets included in the CIP Index

Economy	Proportion of medium- and high-tech industry value added in total manufacturing value added (percent) 2017	Manufacturing value added per capita (2010 $) 2017	Manufacturing value added as a proportion of GDP (percent) 2017
Saudi Arabia	39.22	2,576	12.44
Indonesia	35.35	888	21.50
India	42.87	330	16.86
Lithuania	24.89	3,065	18.64
Philippines	43.32	651	22.49
United Arab Emirates	35.92	3,434	8.45
Viet Nam	38.68	309	16.84
Luxembourg	20.02	5,574	5.03
South Africa	24.43	927	12.37
Belarus	38.83	1,468	22.96
New Zealand	18.53	3,696	9.77
Estonia	27.48	2,799	14.68
Islamic Republic of Iran	46.02	868	12.46
Greece	20.03	1,829	8.24
Argentina	26.00	1,487	14.29
Chile	20.96	1,461	9.67
Qatar	47.86	5,961	9.21
Croatia	27.77	1,852	12.38
Bulgaria	29.21	1,113	13.41
Bahrain	22.17	3,315	15.01
Latvia	20.60	1,719	11.11
Trinidad and Tobago	39.60	2,428	15.41
Kuwait	32.87	1,544	4.62
Peru	15.13	795	12.91
Morocco	27.75	534	15.29
Serbia	26.75	728	15.20
Tunisia	28.87	665	15.65
Malta	37.97	2,202	7.65
Costa Rica	16.69	1,273	12.82
Kazakhstan	13.35	1,099	10.10
Ukraine	29.17	305	10.61
Oman	20.64	1,537	9.73
Bolivarian Republic of Venezuela	34.28	1,168	13.13
Colombia	23.33	835	10.99
Egypt	18.38	410	14.87
Bangladesh	9.76	222	20.47
Iceland	13.90	6,281	12.40
North Macedonia	29.61	709	13.51
El Salvador	19.13	749	19.35

Table B2.1 *(continued)*
Sustainable Development Goal 9 targets included in the CIP Index

Economy	Proportion of medium- and high-tech industry value added in total manufacturing value added (percent) 2017	Manufacturing value added per capita (2010 $) 2017	Manufacturing value added as a proportion of GDP (percent) 2017
Guatemala	22.40	567	18.15
Sri Lanka	8.87	608	15.41
Panama	6.40	577	5.07
Uruguay	15.29	1,742	12.15
Bosnia and Herzegovina	17.29	672	12.08
Eswatini	2.23	1,361	34.01
Jordan	23.66	504	15.58
Pakistan	24.62	156	13.02
Lebanon	15.57	361	5.09
Brunei Darussalam	3.32	4,697	14.94
Mauritius	5.24	1,252	12.30
Hong Kong SAR, China	37.38	498	1.31
Botswana	5.79	474	6.30
Cambodia	0.26	194	17.08
Myanmar	7.62	292	23.46
Ecuador	13.57	638	12.22
Cyprus	23.68	867	4.06
Honduras	7.16	356	16.17
Georgia	8.58	466	11.44
Algeria	2.69	207	4.31
Côte d'Ivoire	14.99	237	14.41
Namibia	7.35	600	10.22
Paraguay	21.83	439	10.81
Armenia	4.62	435	9.68
Plurinational State of Bolivia	9.70	277	11.00
Jamaica	18.77	362	7.52
Nigeria	33.44	223	9.26
Lao People's Dem. Rep.	3.77	193	10.89
Republic of Congo	2.42	102	3.76
Suriname	11.62	1,416	17.29
Republic of Moldova	19.51	220	11.61
Mongolia	5.37	215	5.34
Barbados	38.11	777	4.91
Albania	4.47	280	5.86
Senegal	21.65	112	9.88
State of Palestine	2.52	268	11.28
Kenya	14.98	116	9.92
Gabon	5.39	403	4.70
Fiji	7.09	479	11.16

Table B2.1 *(continued)*
Sustainable Development Goal 9 targets included in the CIP Index

Economy	Proportion of medium- and high-tech industry value added in total manufacturing value added (percent)	Manufacturing value added per capita (2010 $)	Manufacturing value added as a proportion of GDP (percent)
	2017	2017	2017
Azerbaijan	19.05	323	5.59
Syrian Arab Republic	21.52	55	3.30
Cameroon	7.61	212	14.03
Kyrgyzstan	2.71	147	13.54
Bahamas	27.77	599	2.34
Montenegro	14.86	315	4.08
Zambia	9.73	131	8.03
Papua New Guinea	12.61	54	2.35
Ghana	0.80	91	5.05
Zimbabwe	21.82	76	8.21
Belize	18.46	360	8.42
Madagascar	3.56	57	11.60
United Republic of Tanzania	6.47	58	6.78
Central African Republic	9.25	79	23.58
Tajikistan	2.19	120	12.41
Uganda	11.07	55	8.79
Angola	3.37	257	7.63
Nepal	8.38	40	5.41
Mozambique	10.89	46	8.76
Saint Lucia	7.83	184	2.51
Cabo Verde	27.10	208	5.88
Bermuda	27.06	795	0.93
Haiti	5.26	76	10.31
Malawi	11.34	46	9.47
Rwanda	6.66	46	6.01
Yemen	2.06	31	6.58
Ethiopia	16.07	28	5.60
Maldives	2.63	191	2.21
Afghanistan	9.51	66	10.52
Niger	16.86	24	6.16
Macao SAR, China	6.30	177	0.32
Iraq	6.91	47	0.87
Gambia	3.90	25	4.68
Burundi	2.57	24	10.80
Eritrea	4.31	35	5.80
Tonga	1.61	244	6.26

Note: Economies are ordered according to their Competitive Industrial Performance (CIP) Index in 2017. The present table is based on official data, but estimates were made for missing values and outliers following the procedures in UNIDO (2019b). See Annex C.2 for the technology classification of manufacturing activities.
Source: UNIDO elaboration based on the Competitive Industrial Performance Index 2019 database (UNIDO 2019c).

Annex C.1

Country and economy groups

Table C1.1
Countries and economies by industrialization level and geographical region

INDUSTRIALIZED ECONOMIES				
Asia and Pacific				
Australia[a,b,c]	Hong Kong SAR, China[a]	Kuwait	New Zealand[a,c]	United Arab Emirates
Bahrain	Israel[a]	Macao SAR, China	Qatar	
French Polynesia	Japan[a,b,c]	Malaysia[a]	Singapore[a,c]	
Guam	Korea, Republic of[a,b,c]	New Caledonia	Taiwan Province of China[b]	
Europe				
Andorra	Estonia[a,b,c]	Ireland[b]	Monaco	Slovakia[a,b,c]
Austria[a,b,c]	Finland[a,b,c]	Italy[a,b,c]	Netherlands[a,b,c]	Slovenia[a,b,c]
Belarus	France[a,b,c]	Liechtenstein	Norway[a,b,c]	Spain[a,b,c]
Belgium[a,b,c]	Germany[a,b,c]	Lithuania[a,b,c]	Portugal[a,b,c]	Sweden[a,b,c]
Czechia[a,b,c]	Hungary[a,b,c]	Luxembourg[b]	Russian Federation a[b]	Switzerland[b]
Denmark[a,b,c]	Iceland[a]	Malta[a,b]	San Marino	United Kingdom[a,b,c]
Latin America and the Caribbean				
Aruba	Cayman Islands	French Guiana	Trinidad and Tobago	
British Virgin Islands	Curaçao	Puerto Rico	United States Virgin Islands	
North America				
Bermuda	Canada[a,b,c]	Greenland	United States[a,b,c]	
EMERGING INDUSTRIAL ECONOMIES				
Africa				
Egypt	Mauritius	South Africa[a]	Tunisia[a]	
Asia and Pacific				
Brunei Darussalam	India[a,b]	Iran, Islamic Republic of	Oman	Thailand[a]
China[a,b,c]	Indonesia[a,b]	Kazakhstan[a]	Saudi Arabia[a]	
Europe				
Bulgaria[a,b]	Greece[a,b,c]	Poland[a,b,c]	Turkey[a,b,c]	
Croatia[a,b]	Latvia[a,b]	Romania[a,b,c]	Ukraine	
Cyprus[a,b]	North Macedonia	Serbia		
Latin America and the Caribbean				
Argentina[a,c]	Chile[a,c]	Costa Rica[a]	Peru[a]	Uruguay
Brazil[a,b]	Colombia[a]	Mexico[a,b,c]	Suriname	Venezuela, Bolivarian Republic of
OTHER DEVELOPING ECONOMIES				
Africa				
Algeria	Congo, Republic of the	Gabon	Morocco[a]	Seychelles
Botswana	Côte d'Ivoire	Ghana	Namibia	Zimbabwe
Cabo Verde	Equatorial Guinea	Kenya	Nigeria	
Cameroon	Eswatini, Kingdom of	Libya	Réunion	

Table C1.1 *(continued)*
Countries and economies by industrialization level and geographical region

OTHER DEVELOPING ECONOMIES				
Asia and Pacific				
Armenia	Korea, Democratic People's Republic of	Mongolia	Samoa	Uzbekistan
Azerbaijan	Kyrgyzstan	Pakistan	Sri Lanka	Viet Nam
Cook Islands	Lebanon	Palau	Syrian Arab Republic	
Fiji	Maldives	Palestine, State of	Tajikistan	
Iraq	Marshall Islands	Papua New Guinea	Tonga	
Jordan	Micronesia, Federated States of	Philippines[a]	Turkmenistan	
Europe				
Albania	Bosnia and Herzegovina	Georgia	Moldova, Republic of	Montenegro
Latin America and the Caribbean				
Anguilla	Bolivia, Plurinational State of	El Salvador	Honduras	Panama
Antigua and Barbuda	Cuba	Grenada	Jamaica	Paraguay
Bahamas	Dominica	Guadeloupe	Martinique	Saint Kitts and Nevis
Barbados	Dominican Republic	Guatemala	Montserrat	Saint Lucia
Belize	Ecuador	Guyana	Nicaragua	Saint Vincent and the Grenadines
LEAST DEVELOPED COUNTRIES				
Africa				
Angola	Congo, Democratic Republic of the	Lesotho	Niger	Sudan
Benin	Djibouti	Liberia	Rwanda	Tanzania, United Republic of
Burkina Faso	Eritrea	Madagascar	São Tomé and Príncipe	Togo
Burundi	Ethiopia	Malawi	Senegal	Uganda
Central African Republic	Gambia	Mali	Sierra Leone	Zambia
Chad	Guinea	Mauritania	Somalia	
Comoros	Guinea-Bissau	Mozambique	South Sudan	
Asia and Pacific				
Afghanistan	Cambodia	Myanmar	Timor-Leste	Yemen
Bangladesh	Kiribati	Nepal	Tuvalu	
Bhutan	Lao People's Democratic Republic	Solomon Islands	Vanuatu	
Latin America and the Caribbean				
Haiti				

a. Included in OECD Inter-Country Input-Output (ICIO) tables (OECD 2016,2018b).
b. Included in World Input-Output Database (WIOD) (Timmer et al. 2015).
c. Included in the Analytical Business Enterprise R&D database (OECD 2018a).
Note: Industrialized economies include economies with adjusted manufacturing value added (MVA) per capita higher than $2,500 (international PPP) or a gross domestic product higher than $20,000. Emerging industrial economies include economies with adjusted MVA per capita ranging between $1,000 (international PPP) and $2,500 or whose share of the world MVA is higher than 0.5 percent. The list of least developed countries is based on decisions of the United Nations General Assembly. All remaining economies are included in the group "other developing economies."
Source: UNIDO elaboration based on UNIDO (2019f).

Annex C.2

Classification of manufacturing sectors by technology groups

Table C2.1
Definition of medium- and high-technology manufacturing exports

Standard International Trade Classification Rev. 3 codes of medium- and high-technology exports
266t267
512t513, 525, 533, 541t542, 553t554, 562, 571t575, 579, 581t583, 591, 593, 597, 598
653, 671t672, 678
711t714, 716, 718, 721t728, 731, 733, 735, 737, 741t749, 751t752, 759, 761t764, 771t776, 778, 781t786, 791t793
811t813, 871t874, 881t882, 884t885, 891

Source: UNIDO elaboration based on UNIDO (2017c).

Table C2.2
Technology classification of industrial activities

International Standard Industrial Classification Rev. 4	Description	Technology group
10	Manufacture of food products	Low
11	Manufacture of beverages	Low
12	Manufacture of tobacco products	Low
13	Manufacture of textiles	Low
14	Manufacture of wearing apparel	Low
15	Manufacture of leather and related products	Low
16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Low
17	Manufacture of paper and paper products	Low
18	Printing and reproduction of recorded media	Low
19	Manufacture of coke and refined petroleum products	Medium-low
20	Manufacture of chemicals and chemical products	Medium-high and high
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	Medium-high and high
22	Manufacture of rubber and plastics products	Medium-low
23	Manufacture of other non-metallic mineral products	Medium-low
24	Manufacture of basic metals	Medium-low
25	Manufacture of fabricated metal products, except machinery and equipment	Medium-low
26	Manufacture of computer, electronic and optical products	Medium-high and high
27	Manufacture of electrical equipment	Medium-high and high
28	Manufacture of machinery and equipment not elsewhere classified	Medium-high and high
29	Manufacture of motor vehicles, trailers and semi-trailers	Medium-high and high
30	Manufacture of other transport equipment	Medium-high and high
31	Manufacture of furniture	Low
32	Other manufacturing	Low

Source: UNIDO elaboration based on OECD (2011), adapted from ISIC rev. 3 to ISIC rev. 4.

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José Antonio Ocampo, Central Bank of Colombia and Columbia University

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