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TOOL 8

DIGITAL READINESS DIAGNOSTICS

Stairway to Industry 4.0 and digital technology competitiveness

EQuIP

Enhancing the Quality of Industrial Policies

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Name of tool	**Digital Readiness Diagnostics: Stairway to Industry 4.0**
Objective	This tool offers policymakers guidance on how to evaluate a country's readiness to address the opportunities and challenges arising from digitalization of manufacturing. It provides insights into practical approaches to policymaking, methodologies, and empirically tested role models to inform digitalization agendas and efforts to promote industrialization, aligning these with long-term national development strategies.
Key questions	• Is the country ready for the digitalization of manufacturing? • Which sets of foundational capabilities are needed to digitalize? • Does the country possess a sufficient range of different foundational capabilities? • What is the sector-specific potential of advanced digital production technologies? • Which foundational capabilities gaps exist? • How does the country perform globally in terms of its readiness for digitalization? • How does the country perform relative to its different income group comparators? • Which policies have other countries formulated to build foundational capabilities and move up the digitalization ladder? • Which major advanced digital production technologies have not yet been imported and must be prioritized? • Has the country been sufficiently exposed to production technologies with digital potential? • Has the country absorbed advanced production technologies through imports, including services, parts and instrumentation? • Is the country exporting advanced digital production technologies? • Is the country developing a competitive advantage in any specific advanced digital production technologies? • What sector and policy areas require prioritization?
Capacity and capability indicators used	• Electric power consumption: kWh per capita per year • Percentage of firms experiencing electrical outages • Fixed broadband subscriptions (100 users) • Mean download speed (Mbps) • Share of manufacturing in total gross fixed capital formation • Mean years of schooling • ISO 9001 certificates per 1,000 population • Intellectual property rights payments • Percentage of science, technology, engineering, mathematics (STEM) graduates • Enrolment ratio in tertiary education • Expenditure in research and development (R&D) as a share of gross domestic product (GDP) • Scientific and technical journal articles per million population* • Total patents in force per USD 100 billion GDP* • Intellectual property rights receipts*
Competitiveness indicators used	• Imports and exports of production technologies with digital potential* • Imports and exports of advanced digital production technologies (total, final products, parts)* • Imports and exports of instrumentation technologies* • Imports of computer and information services*

* Indicator that represents a relatively complex concept, is more complex in its calculation or requires more or detailed data.

Abbreviations

ADAS	Advanced Driving Assistance Systems
ADP(T)	Advanced Digital Production (Technologies)
AI	Artificial Intelligence
ASEAN	Association of Southeast Asian Nations
AUV	Autonomous Underwater Vehicles
BEC	Broad Economic Category
CoRe	Centre of Robotic Excellence
C3IS	Command, Control, Communication and Information Systems
DISF	Domestic Investment Strategic Fund
DPT	Digital Production Technology
DST	Department of Science and Industry
DTI	Department of Trade and Industry
EQuIP	Enhancing the Quality of Industrial Policy
E&P	Exploration, Development and Production
GAN	Generative Adversarial Network
GDP	Gross Domestic Product
GERD	Gross Expenditure in Research and Development
GFCF	Gross Fixed Capital Formation
GTD	Generation, Transmission and Distribution
GVC	Global Value Chain
HIF	High Impact Fund
HIS	High Throughout Screening
HSE	Health, Security and Environmental
ICT	Information and Communication Technologies
IDR	Industrial Development Report
IIoT	Industrial Internet of Things
IMR	Inspection, Maintenance and Repair
IoT	Internet of Things
IPR	Intellectual Property Rights
ISIC	International Standard Industrial Classification of All Economic Activities
ISID	Inclusive and Sustainable Industrial Development
ISO	International Organization for Standardization
ITU	International Telecommunication Union
kWh	Kilowatt hour

LIC (or LI)	Low Income-Countries
LMIC (or LMI)	Lower Middle-Income Countries
Mbps	Mean download speed
MEB	Malaysian Educational Blueprint
MEMS	Micro-Electro-Mechanical Systems
M&E	Monitoring and Evaluation
MOE	Ministry of Education
MITI	Ministry of International Trade and Industry
MNC	Multinational Corporation
NFV	Network Function Virtualization
NIS	National Innovation System
NLP	Natural Language Processing
OECD	Organisation for Economic Cooperation and Development
OEM	Original Equipment Manufacturer
PLN	Personal Learning Network
PTDP	Production Technologies with Digital Potential
R&D	Research and Development
RTO	Research Technology Organization
SDN	Software-defined Network
SITC	Standard international trade classification
SoCs	Systems on Chips
STEM	Science, Technology, Engineering, Math
THRIP	Technology and Human Resources for Industry Programme
UAV	Unmanned Aerial Vehicle
UIS	UNESCO Institute for Statistics
UMIC (or UMI)	Upper Middle Income-Countries
UNESCO	United Nations Educational, Scientific and Cultural Organization
V2V	Vehicle-to-Vehicle
WIPO	World Intellectual Property Organization
4IR	Fourth Industrial Revolution

1 Introduction

The Fourth Industrial Revolution (4IR) is transforming manufacturing as a driver of development (IDR 2020, UNIDO). Like previous technological revolutions, the 4IR has opened windows of opportunities for driving inclusive and sustainable industrial development across countries and regions. Digital technologies are considered crucial in addressing global development challenges, such as climate change and other issues outlined in the UN Sustainable Development Goals and Agenda 2030 (IDR 2022, UNIDO). National governments are expected to remain in the driver's seat, determining the necessary conditions and fostering the capabilities required by domestic agents to endorse the rapidly changing dynamics of digitalization in global manufacturing. But are governments ready to facilitate the digitalization of manufacturing in their countries?

Analytical framework

Context and definitions

The emergence, deployment and diffusion of new digital technologies clustered around the 4IR is increasingly altering the nature of manufacturing production, while blurring the boundaries between physical and digital production technologies and systems. Advances in fields such as intelligent automated systems, robotization and additive manufacturing as well as related data analytics—Internet of Things (IoT), digital platforms and digital supply chains—open opportunities to accelerate technological and organizational innovation with a profound impact on the modes and social conditions of production, in particular business models and employment. Indeed, technological and organizational change are deeply intertwined.

The 4IR encompasses different types of digital technologies that are altering production and service activities within and across sectoral value chains.[1] At the centre of the 4IR lies a widespread process of digitalization. In some cases, these digital technologies combine and merge the physical and digital realms of both production and products, hence changing both the patterns of production and of consumption. When discussing digitalization, however, we must first clarify what we mean by that term, as the concept is not yet well-defined in the literature. Some authors use the term to refer to the 'digital economy', a term that is often used for platform-enhanced e-commerce, online services (such as Netflix, Spotify, Zoom), ride- or real-state-sharing apps (Uber, Airbnb), etc.

From a manufacturing perspective, the term digitalization can be used more narrowly to refer to the digitalization of productive activities and tasks, especially manufacturing systems, as well as closely related digital infrastructure that support such activities. In that sense—and with a focus on manufacturing production—we move towards the narrower concept of Industry 4.0[2] (IDR 2020,

[1] See also EQuIP Tool 4 on global value chains.

[2] The concept of Industry 4.0 stem from policy programmes adopted around the world, such as Industry 4.0 in Germany and Made in China 2025 (Li, 2018), which have a profound impact on how we perceive and forecast the adoption of these technologies (Pardi et al., 2020; Andreoni et al., 2020).

UNIDO). Focussing on the manufacturing realm, digitalization is associated with the adoption of advanced digital production (ADP) technologies, which can be grouped into three main clusters:

1) Artificial intelligence (AI), data analytics and cloud computing;
2) Robotics, cyber-physical systems and additive manufacturing; and
3) IoT and network technologies.

Digitalization implies the increasing importance of foundational capabilities to absorb, adapt, combine and implement these technologies in production as opposed to simply developing individual technological capabilities. For example, sensorization of automated production technologies (Cluster 2) becomes important when data can be collected, analysed and used to improve efficiency, re-design processes and enhance resilience within firms (Cluster 1) along value chains (Cluster 3). Certain capabilities are essential in many of these inter-dependent ADP technology clusters, that is, they are pre-conditions for advanced digital production to be effectively implemented.

The boundaries between the three ADP technology clusters are blurry and are continuously redefined by digital innovation, with multiple applications across different areas of firm activities (Error! Reference source not found.). In industry, combinations of these ADP technologies are implemented in systems constructed of highly complementary sub-systems and technologies.

Box 1. Advanced digital production (ADP) technologies

ADP technologies are multi-purpose technology clusters that integrate software, hardware and connectivity with applications in various areas of production.

i. Research and development (R&D), design, pre-manufacturing innovations, such as the virtualization of the product development stage by using virtual/augmented reality and faster prototyping using 3D printing.
ii. Process innovations, such as smart production, predictive maintenance, and enhanced process and quality control.
iii. Product innovations, such as smart and connected wearables, household appliances, vehicles and highly customized products such as 3D printed clothes or personalized drugs.
iv. Supply chain management and business model innovations enabled by the increased tracking and monitoring of products both upstream and downstream on the production chain, real-time demand, product usage monitoring, and improved decision-making with insights originating from business-related data analytics.

Source: Andreoni et al. (2021)

As Andreoni et al. (2021) point out, the truly new and potentially revolutionary aspects of these ADP technologies are their ‘technology fusion’ characteristics (**Box 2**). That is, the most disruptive impacts are associated with the combination and purposeful system integration of technologies from traditionally separate fields of knowledge. This is even more evident when we consider three other complementary technological clusters, namely advanced materials, nanotechnologies and biotechnologies (IDR 2020, UNIDO).

Box 2. Technology fusion: a definition

Technology fusion is a process of technology innovation resulting from the integration of a closely complementary but dissimilar set of capabilities from different technology clusters and domains of the 4IR, resulting in new technology systems.

Source: Andreoni, et al. 2021

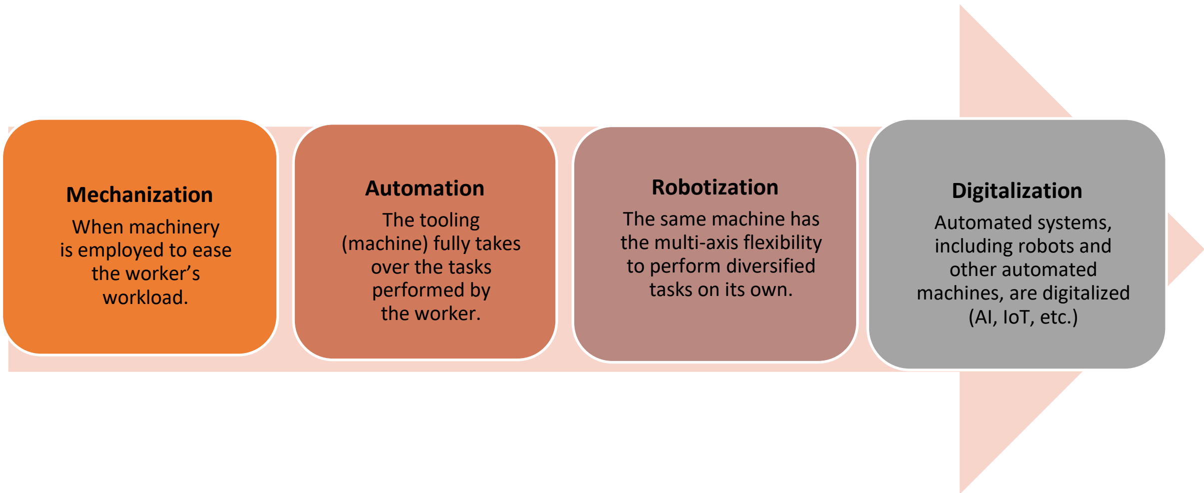
Because technology fusion underpins ADP technologies, industry and firms must simultaneously develop capabilities in several knowledge domains and continue to do so at increasing speeds. Capabilities in one digital sub-system or technology cluster are not sufficient to master ADP technologies and maximize their potential.

Evolution or revolution?

While often presented as disruptive technological changes, many of today's 4IR production technologies have evolved and emerged from the same engineering and organizational principles of previous industrial revolutions. It has been argued that from a historical perspective, we are facing an 'evolutionary transition' today rather than a 'revolutionary disruption' (Andreoni and Anzolin, 2019).

Mechanization and automation trends are not new; they have been evolving for decades, especially in advanced manufacturing sectors (**Figure 1**). Although the two concepts are similar, they are treated in sequential order.

Figure 1. From mechanization to digitalization



Source: Authors

Mechanization, understood as the replacement of human labour by machine labour, is a process that started between the first and second industrial revolution. During that time, the steam engine and machine's electrification replaced physical efforts, often complementing human labour. The more intelligent and sophisticated form of mechanization, whereby the machine replaces human mental processes, is referred to as *automation*, and represents a situation where—within certain limits—the machine selects its own programme and can reprogramme itself.

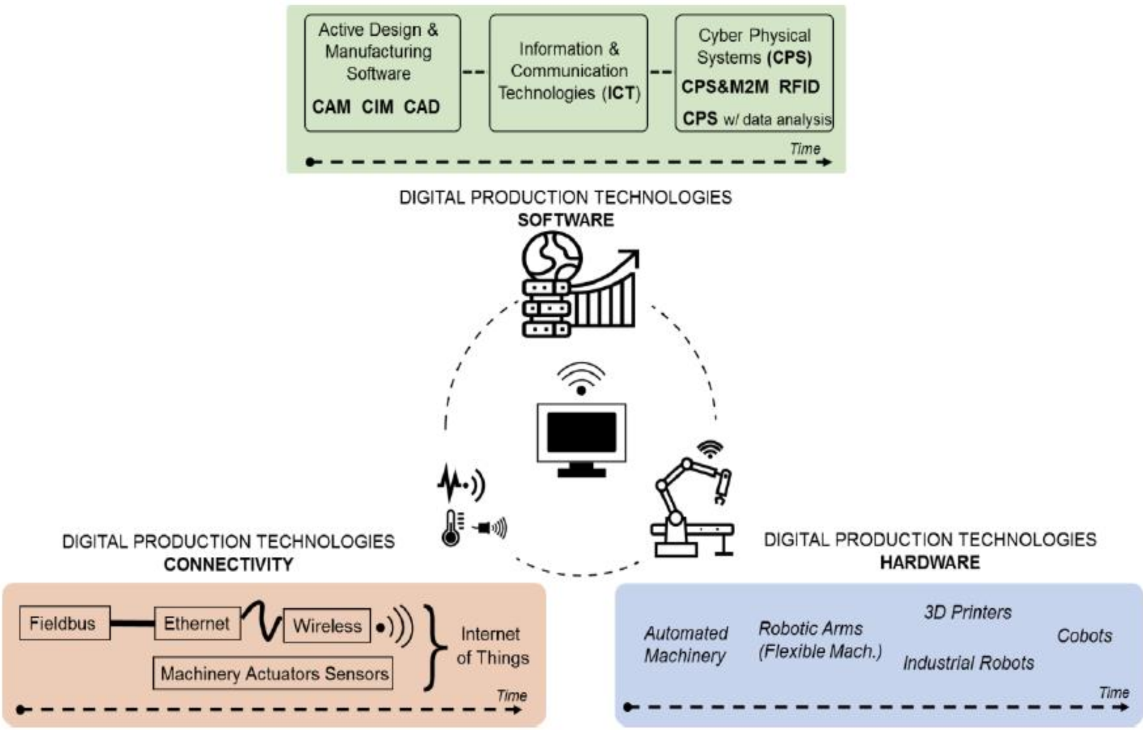
A more recent step in the automation-related technological change is robotics, which adds an extra layer of complexity to the execution of tasks, with machines becoming flexible enough to perform different tasks: once the machine is programmed, it has the capability of changing the type and intensity of tasks, with increasing ability to self-regulate. Industrial robots today are defined according to ISO 8373:2012 as "an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications". This type of robot is an evolution of the robotic arm system, with more flexibility in terms of computer reconfiguration but constrained in terms of task variety. Even more recently, during the so-called *second machine age*, the concepts of automation and robotization evolved further and were integrated with digitalization. This latter step implies automated systems, including robots and other automated machines, that are capable of directing physical labour and of undertaking cognitive tasks in an autonomous and intelligent way, i.e. learning to use neural networks with large data sets through AI and IoT technologies (Brynjolfsson and McAfee, 2014; Harteis, 2018; Arslan et al., 2021).

More specifically, this latter stage of the evolution of automation technologies entails two interrelated processes: digitization and digitalization. The former refers to the conversion of analogue into digital information; in other words, the process of converting physical space into digital information (i.e. into bits, bytes), taking advantage of the enhanced possibilities of data creation, processing and storage (Fernandez-Macias, 2018). The latter, digitalization, is a more far-reaching phenomenon (Peruffo et al., 2017), whereby digitization is a precondition for businesses to convert their processes with the use of digital technologies. When applied to the manufacturing sector, digitalization implies the establishment of connecting networks between machines, and the use of data analytics and digital databases for monitoring, controlling and optimizing interconnected work processes (Hirsch-Kreinsen and Hompel, 2017).[3]

Automation and digitalization lie at the very core of ADP technologies of the 4IR. ADP technologies are the latest step in the development of traditional industrial production technologies. They result from incremental changes in the hardware of these machines, and their software, i.e. their functionalities and data use in a cyber-physical space, and connectivity, i.e. their integration with other production technologies (and products). Improvements in the hardware, software and connectivity of production technologies have enhanced the possibilities for production system integration – its virtual design, digital control and reconfiguration. **Figure 2** is a schematic model of ADP technologies' three main components. These are hardware, software and connectivity; the figure presents the evolution and interdependencies linking these components.

[3] https://insights.sap.com/digitization-vs-digitalisation/

Figure 2. ADP technology: components and evolution

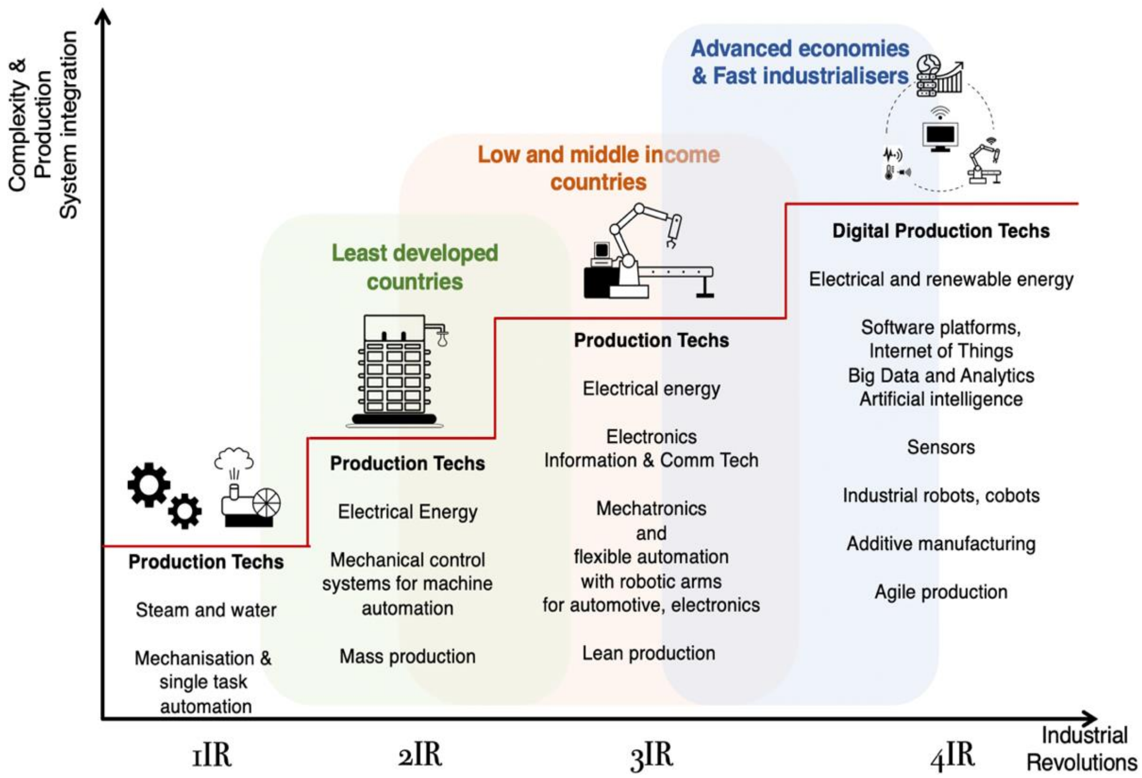


Source: Andreoni and Anzolin, 2019; see also IDR 2020, UNIDO

Against the backdrop of digitalization, the reality policymakers in many of today's developing countries face differs significantly from that faced in advanced economies. Productive sectors in developing countries are still stuck in the second industrial revolution, with most struggling to effectively engage with the technological, organizational and institutional innovations of the third industrial revolution (WEF, 2018; UNIDO, 2020).

Figure 3 illustrates the developing countries' multiple and simultaneous challenges, which need to be addressed at an increasingly faster rate driven by digitalization (Whittaker et al., 2020). Governments in developing countries need to invest in a massive expansion of basic technical skills to generate formal employment opportunities for youths. At the same time, governments must invest in new digital skills and more advanced STEM subjects to build a new economy and provide better job opportunities in the future. Some of the basic technical skills needed evolved during the third industrial revolution. Yet emerging technologies call for a new set of digital skills, for example programming skills, web and application development skills, digital design, data management, visualization and analytics, which build on advanced literacy, numeracy and information and communication technology (ICT) skills. Given that digital technologies draw on and integrate different science and technology fields in new ways ('technology fusion'), traditional training often does not prepare for the use of integrated technologies. The need for training in the deployment of mechatronics or design of digital platform interfaces integrating hardware, software and connectivity solutions significantly raises the digital skills development challenge (Andreoni et al., 2021b).

Figure 3. Digitalization in the era of compressed development



Source: Andreoni and Anzolin, 2019

Foundational capabilities

Capturing the potential benefits of digitalization in developing countries is conditional on addressing the challenges around the development of the foundational capabilities that are necessary to climb up the digitalization stairway (**Figure 3**). Foundational capabilities go beyond those related to individual digital technologies such as robots or AI and are necessary to effectively participate in digitalization.

Some of these foundational capabilities are transversal, i.e. they are essential for all sectors of the economy, from agriculture to advanced manufacturing and integrated services. Others are more sector-specific, that is, ADP technologies and skills are used for different sectoral applications. Being able to assess the country's level of foundational capabilities and the different potential opportunities they offer in specific sectors is key for governments' decisions and prioritizations in digital industrial policymaking.

Box 3. Foundational capabilities: A definition

Foundational capabilities are the 'capabilities to learn new technical and organisational solutions, integrate them into production, organise and commit resources over time for the effective deployment of these new solutions'.

Source: Andreoni et al. 2021

The development of foundational capabilities is a gradual process, with several ingredients being preconditions for effectively moving forward in the digitalization process. The foundational capabilities for effective absorption and deployment of ADP technologies towards Industry 4.0 consist of three main elements.

Enabling infrastructure (energy and digital): Digital production technologies place significant demands on the infrastructure required for their use in productive activities and the economy as a whole. Among other things, ADP technologies require stable electricity and high-speed low-latency internet connectivity. Digitalization is simply not possible in the absence of a reliable network with adequate territorial coverage of such energy and digital infrastructures. Developing countries face significant challenges in terms of providing affordable and reliable electricity and adequate connectivity. In some cases, off-grid energy technologies and wireless connectivity systems are being used to address infrastructural bottlenecks. While these solutions work in certain areas, they are not always able to provide the quality and reliable services needed to effectively run digital production technologies. As a result, the productivity and quality improvements of digital production technologies are offset by these infrastructural bottlenecks and can make technology investments by individual firms too risky and ultimately cost ineffective.

Production capabilities (basic and intermediate): Investments in ADP technologies can only be made and used by firms that have sufficiently sustained levels of productivity and operational efficiency, long-term investment in fixed capital, a relatively skilled workforce and hence, some degree of technology absorption capacity. This introduces a very specific challenge in developing countries. Companies with the ability to make technology investments have already committed their resources otherwise and must assess how they can retrofit and integrate new digital production technologies into their existing production plants. Establishing brand new plants is an exception, as it requires significant long-term investments and access to markets. New plants might be difficult to manage given the lack of basic and digital infrastructure. ADP technologies are often used to retrofit existing productive activities. The integration of sensors into machines, factories and products is key for digitalizing production and enabling machinery to collect data. Thus, the presence of production capabilities—established firms with basic productive and intermediate organizational capacity—is a pre-requisite for most digitalization efforts.

Innovation capabilities (basic and intermediate): Innovation capabilities are crucial for the adoption and adaptation of ADP technologies to local conditions. This entails not only dynamic, firm-level capabilities, i.e. capabilities to procure, invest, retrofit, redesign and retrain the workforce, but also a well-developed national system of innovation, with universities, research and technology organizations (RTOs), a specialized and skilled workforce, and clear regulations for new technologies.

Individual 4IR technologies cannot be effectively absorbed and deployed without these foundational capabilities. Most ADP technologies in developing countries, such as automated machineries, additive manufacturing and digital production cells, are imported from industrialized and emerging economies. The production technologies imported may not yet be digital or fully digital, but have the potential to be digitalized and offer an important opportunity for learning and retrofitting. For example, machine tools that can be used autonomously or as part of digitalized production systems. In other cases, countries import ADP technologies whose adoption and adaptation to the local context require the foundational capabilities discussed above. Foundational capabilities are essential in both cases for learning in the process of technology absorption, retrofitting and effective deployment.

Box 4. Production technology with digital potential (PTDP)

Production technology with digital potential (PTDP) include a wide range of machine tools and tooling and complementary productive equipment whose coordinated and synchronized operations can be potentially enhanced through forms of digital retrofitting such as sensorization, automation and network integration.

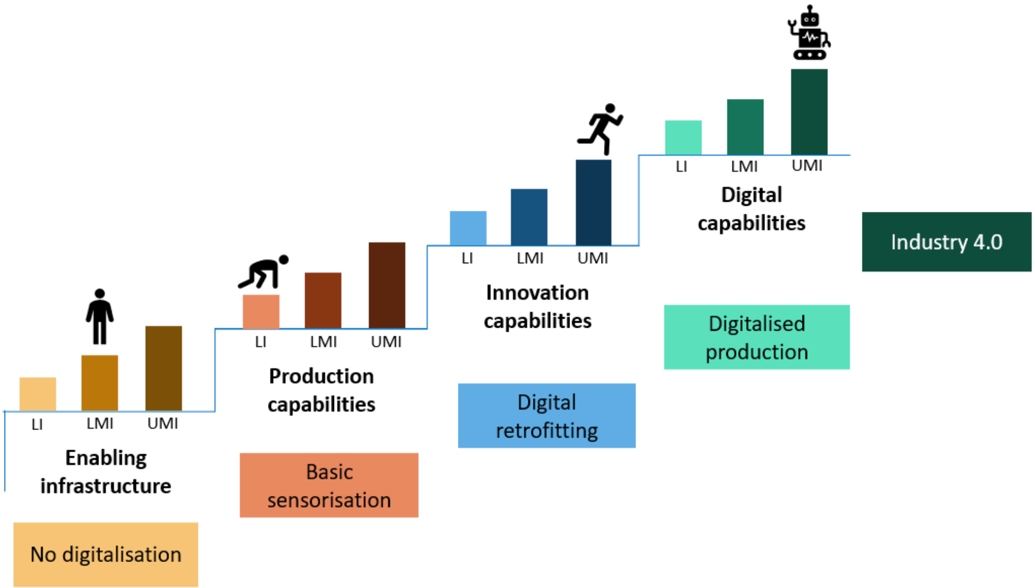
Source: Andreoni and Anzolin, 2019

The lack of foundational capabilities makes it difficult to exploit the opportunities presented by technology fusion in key 4IR technologies, such as advanced materials, intelligent automated systems, robotization, additive manufacturing, data analytics, IoT and digital platforms. Combining different technologies is, of course, not a new phenomenon. Technology has always operated within systems, often incorporating technologies with different origins. In the 4IR context, however, systems seem to be reaching a new level of complexity and interdependency between traditionally separate and specialized fields of knowledge. This growing level of technology fusion requires interactions among many different actors, which enhances their development and application; hence, the increasing importance of establishing 'ecosystems' of actors who collaborate within networks (instead of chains) in a unified digital platform.

Technology fusion is a demanding process that involves the development and accumulation of foundational and advanced capabilities across multiple technology domains. This process creates certain opportunities because the application of these technologies in specific sectors can reshape sectoral landscapes and boundaries, pave the way for new processes of diversification, and open new opportunities for value creation and capture.

According to UNIDO IDR (2020), the digitalization of manufacturing is a cumulative process that builds on the knowledge gained from exposure to industrialization. Hence, the 'capability development pathway' (Figure 4) that countries must follow to join the digitalization trend largely depends on the state of development of foundational capabilities, the level of a country's exposure to imported semi- or fully digitalized production technologies, and the ability to develop those capabilities through targeted industrial policy interventions.

Figure 4. Stairway to Industry 4.0



Source: Authors

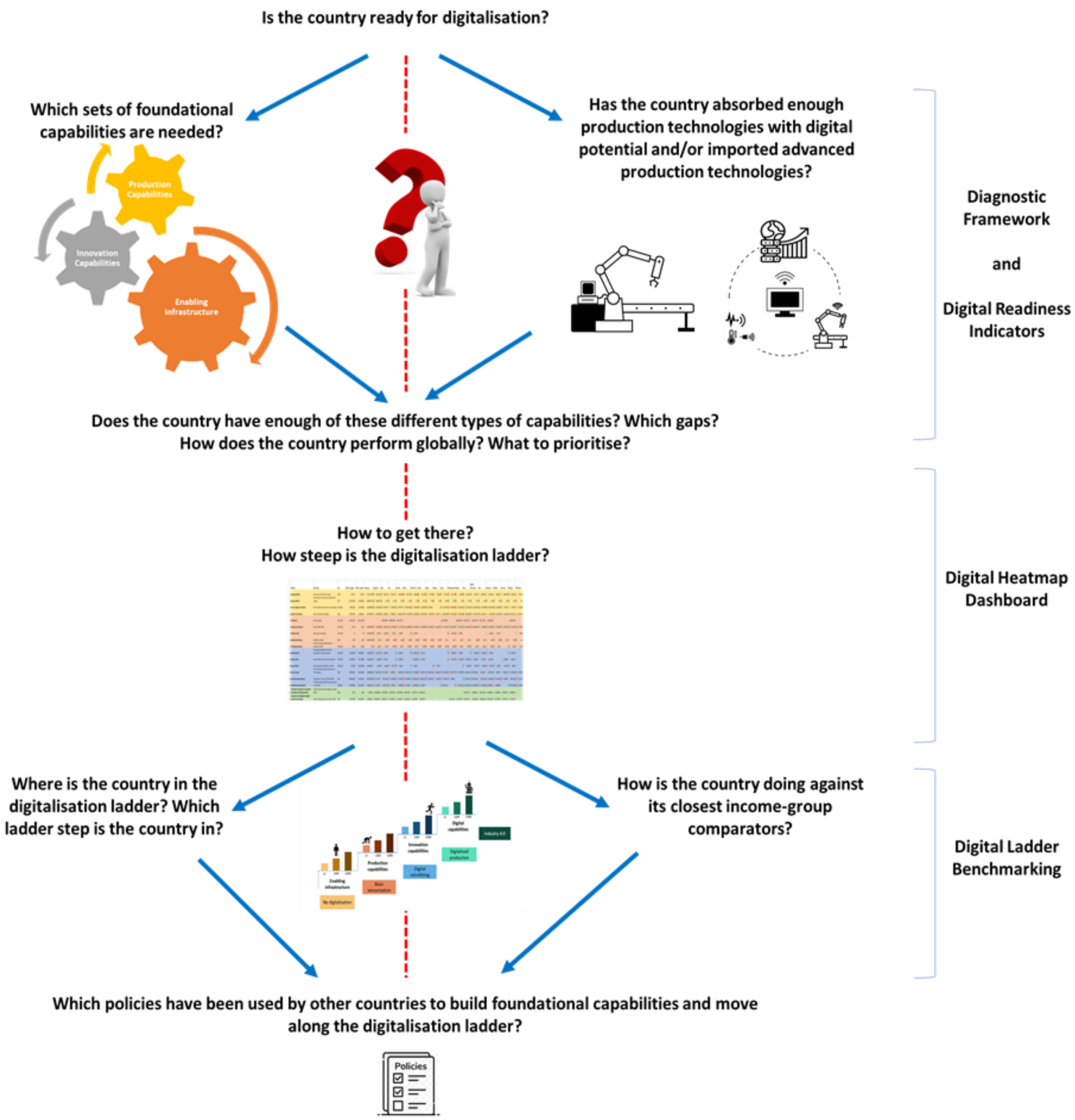
These observations have clear-cut policy implications. Although it may be possible in low-income countries to skip certain steps in technology, it is not possible to skip steps in capability development. A gradual process that involves the development of adequate infrastructure, production capacity and innovation capabilities is necessary, as these foundational capabilities are essential for enabling the deepening of digitalization. Numerous opportunities open up for middle-income countries and their firms, which already possess the necessary foundational capabilities.

Strategically using the 'supply push' and 'demand pull' pressures that different sectors exert in the digitalization process is crucial. Technology diffusion policies are needed for pull sectors to reduce costs and mitigate the risk associated with the adoption and adaptation of ADP technologies. Innovation policies for push sectors should prioritize the promotion of research organizations and digital innovation hubs, the establishment of technological standards, and the building of innovation ecosystems to maximize the benefits of the technology fusion associated with ADP technologies. If adequately promoted through industrial policy, the push-pull dynamics can lead to widespread adoption of ADP technologies, potentially creating specialized suppliers of digital solutions adapted to local needs, which in turn can pave the way for international competitiveness. One example of a push sector is the production of capital equipment with ADP characteristics, while other sectors are mostly users of machinery and equipment featuring advanced digital technologies.

Structure of this tool

This EquIP tool on digitalization offers a comprehensive set of indicators (Section 3) relevant for the digital industrial revolution and digital industrial policy. The indicators are divided into two main sections. The tool first provides a basic set of indicators. This initial layer of analysis is summarized in **Figure 5**:

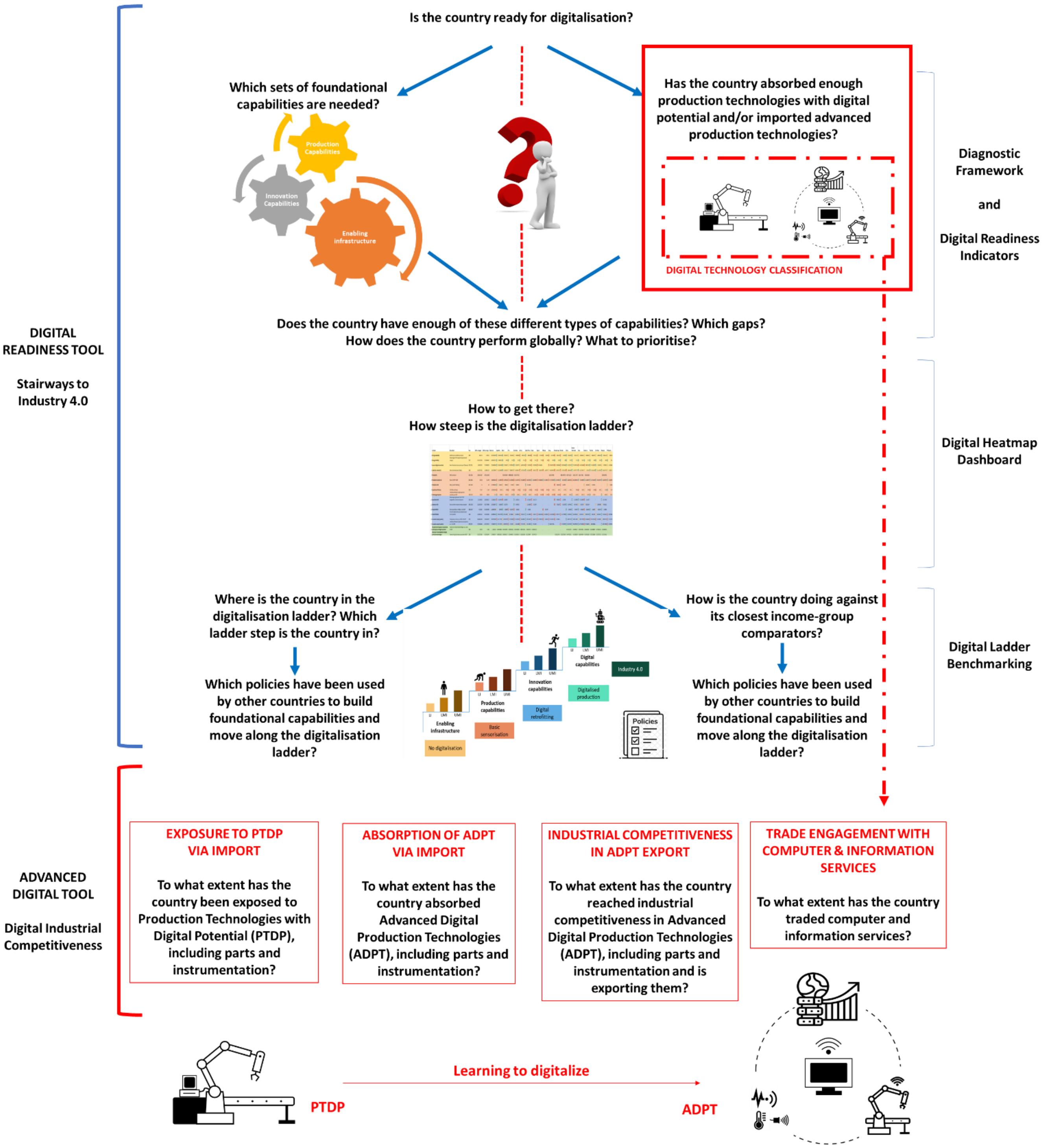
Figure 5. Digital tool, basic analytical framework



Source: Authors

Building on the logic above, an additional set of more advanced indicators extends and completes this tool's analytical framework. These indicators capture the extent of engagement with ADP technologies. This is reflected in the box highlighted in red in **Figure 6.**

Figure 6. Digital tool, advanced analytical framework



Source: Authors

Five elements stand out:

- First, indicators capture the extent to which countries have absorbed and have been exposed (through imports from abroad) to different types of digital production technologies with digital potential (PTDP).
- Second, indicators capture the extent to which countries have directly imported advanced digital production (ADP) technologies, including parts and instrumentation.
- Third, the extent to which countries have become exporters of advanced digital production (ADP) technologies is assessed. Have they gained some level of industrial competitiveness?
- Fourth, the indicators assess the extent to which countries are importers and exporters of digital services measured by trade in computer and information services.
- Finally, a new Digital Technologies Classification is introduced which informs the selection of tradable technologies underpinning the indicators of this advanced digital tool.

Analytical instruments to use the indicators are developed:

- Because countries face different capability gaps, a Digital Heatmap Dashboard (Section 4) is developed as a synthesis and benchmarking tool for policy prioritization.
- A methodology to assess where countries stand on the digitalization ladder in relation to other close country comparators (i.e. within the same intra-country income group) and across other country income groups (low-income, low middle-income and upper middle-income) is introduced – Digital Ladder Benchmarking Tools (Section 3).
- Finally, country case studies are presented to shed light on how developing country governments have designed policies around specific capability gaps to climb the digitalization stairway.

The structure of the remaining document is as follows:

Section 2 discusses the relevance of this tool for industrial policy. **Section 3** introduces the indicators, their calculation and interpretation as well as data sources. **Section 4** presents case studies and discusses the link between indicators and policy. **Section 5** explores links to other EquIP tools, while **Section 6** suggests potential extensions for the type of content and analysis covered in this tool. The **Annex** provides additional technical details.

2 Relevance for the industrial policymaking process

This tool addresses the growing demand of policymakers in developing countries for guidance on evaluating their country's readiness to address the opportunities and challenges arising from the digitalization of manufacturing. It aims to bridge the gap in knowledge on practical approaches to policymaking, methodologies and empirically tested role models that inform digitalization agendas and industrialization efforts aligned with long-term national development strategies.

The tool is intended as a reference for policymakers who are grappling with the following questions: Which strategies to pursue on the path towards 4IR. What concrete measures or tools can be deployed to facilitate 4IR readiness? How to measure progress? What sector and policy areas need prioritization? How to identify possible benchmarks, and how to determine the country's progress relative to its comparators? To what extent is the country exposed to learning from digital technologies through technology imports? What capability gaps are preventing digitalization? Addressing these complex questions is essential for formulating, designing and monitoring digital industrial policy.

3 Methodology and indicators

3.1 Overview of indicators

This tool provides a set of indicators to assess and benchmark a country's

(i) level of readiness for digitalization, and

(ii) the progress it has made in industrial digitalization and its level of industrial competitiveness in ADP technologies, including computer and information services.

The first part of the diagnostics toolkit is structured around the three main clusters of foundational capabilities discussed in Section 0 – energy and digital infrastructure, and basic and intermediate production capabilities and innovation capabilities in terms of both basic innovation efforts and intermediate innovation outputs. Each of these three layers of the diagnostic toolkit features different sets of indicators that capture different foundational capability dimensions.

Capability indicators are widely used by national governments in evidence-based policymaking and by multilateral organizations for country benchmarking. A country's productive capabilities are very distinct and very difficult to measure directly, hence, several proxy indicators at different levels of aggregation (country, sector, firm) are generally used. Some of these proxies measure direct inputs into production and innovation processes responsible for a country's industrial competitiveness performance. Other capability indicators use outputs as ways of capturing performance and—indirectly—the level of capabilities a country must possess to generate such output or competitiveness performance. Capability indicators can be combined to create composite indices. For an example, see UNIDO's Competitiveness Industrial Performance Index (UNIDO, 2002; Andreoni, 2011; UNIDO, 2020).

Box 5. Capability indicators: How to construct them step-by-step

The construction of a capability indicator follows several basic steps:

STEP 1: Identification, definition and theoretical explanation of the capability to measure

STEP 2: Identification of the set of proxies that best capture the selected capability

STEP 3: Analysis of each dataset underpinning the proxies – their sources, time period covered and country coverage

STEP 4: Selection of proxy data, testing and definition of the indicator

STEP 5: Determining the best data variable to scale the indicator, that is, accounting for the country's (or sector or firm's) size (e.g. scalability by population)

STEP 6: Construction of the appropriate scaled indicator (ratio) and data collection

STEP 7: Sensitivity analysis and identification of potential biases in the indicator

STEP 8: Potential extensions of the indicator, including consideration of different levels of aggregation, including the application of sector, product or technology classifications.

Source: Authors

The indicators presented in **Table 1** are country-level diagnostics that capture a country's digital readiness in terms of different types of foundational capabilities.

Table 1. Foundational capabilities

Foundational capabilities (layers)	Dimensions	Indicators	Country coverage LMICs Tot: 135	Coverage period	Source
Enabling infrastructure (Layer 1)	Energy	**Energy availability** Electric power consumption: kWh per capita per year	97	2005–2014	World Development Indicators (World Bank)
		Energy reliability: Percentage of firms experiencing electrical outages	114	2017	World Bank Enterprise Survey
	Digital	**Digital connectivity (wired):** Fixed broadband subscriptions (100 people)	130	2003–2019	ITU, via World Bank
		Quality of connectivity: Mean download speed (Mbps)	194 (total)		M-Lab
Production capabilities (Layer 2)	Basic	**Productive investments:** Share of manufacturing in total gross fixed capital formation	39	Data points	World Bank
		Productive skills: Mean years of schooling	39	Data points	UNESCO
	Intermediate	**Operational efficiency:** ISO 9001 certificates per 1,000 population	116	2019	ISO
		Technology absorption: Intellectual property rights payments (e.g. royalties)	84	1976–2019	International Monetary Fund, Balance of Payments Statistics Yearbook and data files, via World Bank
Innovation capabilities (Layer 3)	Basic: Innovation effort	**Specialized skills:** Percentage of STEM graduates	50	2014–2019	UNESCO UIS
		Advanced skills: Enrolment ratio in tertiary education	74	2014–2019	UNESCO UIS
		Research effort: Gross expenditure in R&D as a share of GDP	48	2013–2018	UNESCO UIS
	Intermediate: Innovation outputs	**Research output:** Scientific and technical journal articles per million population	133	2000–2018	National Science Foundation, Science and Engineering Indicators, via World Bank
		Innovation output (patents): Total patents in force per USD 100 billion GDP	123	2004–2019	WIPO
		Innovation output (property rights): Intellectual property rights receipts (e.g. royalties)	72	1976–2019	International Monetary Fund, Balance of Payments Statistics Yearbook and data files, via World Bank

Source: Authors

The digital readiness analysis is supplemented with a fourth layer of diagnostics that capture a country's exposure to technologies with digital potential (PTDP) and imported advanced digital production (ADP) technologies (**Table 2**).

Specifically, the indicators allow analysts to measure the extent to which firms in a given country have or have not:

- absorbed and been exposed (through imports) to different types of digital production technologies with digital potential (PTDP);
- directly imported advanced digital production (ADP) technologies, including parts and instrumentation;
- become exporters of advanced digital production (ADP) technologies, hence have gained some level of *industrial competitiveness* in digital technologies;
- engaged with digital services through the import and export of computer and information services.

A new *Digital Technologies Classification* is developed to conduct such analyses with the aim of informing the selection of tradable technologies that underpin the indicators.

Box 6. Learning to digitalize: Steps and questions Learning to digitalize: Steps and questions

Learning to digitalize is a production, technological and organizational development process, whereby firms first learn from importing, using and retrofitting production technologies with digital potential, and then increasingly move towards importing, adapting, manufacturing and innovating fully advanced digital production technologies up to exporting and integrating them with digital services.

EXPOSURE TO PTDP VIA IMPORT

To what extent has the country been exposed to Production Technologies with Digital Potential (PTDP), including parts and instrumentation?

ABSORPTION OF ADPT VIA IMPORT

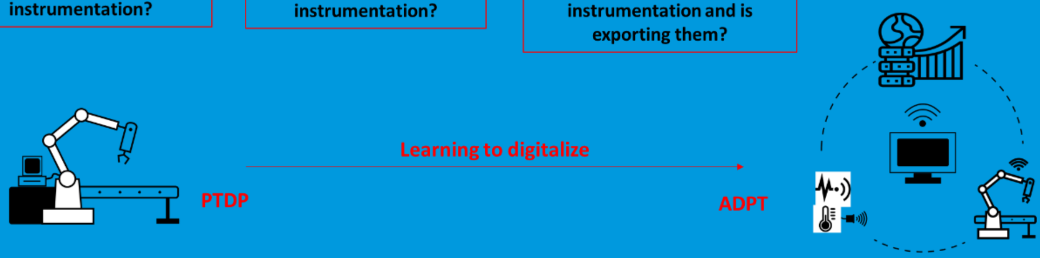
To what extent has the country absorbed Advanced Digital Production Technologies (ADPT), including parts and instrumentation?

INDUSTRIAL COMPETITIVENESS IN ADPT EXPORT

To what extent has the country reached industrial competitiveness in Advanced Digital Production Technologies (ADPT), including parts and instrumentation and is exporting them?

TRADE ENGAGEMENT WITH COMPUTER & INFORMATION SERVICES

To what extent has the country traded computer and information services?



Source: Authors

Table 2. Digital capabilities

Digital capabilities	Dimensions	Indicators	Country coverage LMICs Tot: 135	Coverage period	Source
Import of PTDP and ADPT	**Absorption and exposure to production technologies with digital potential (PTDP)**	**Imports of production technologies** (with potential for automation, sensorization and Industrial Internet of Things (IioT) HS 2017 – code 84-85, intersected with BEC 4 code 41 and 42.	ALL	2002 – HS02 2017 – HS17	UNCOMTRADE
	Deployment and adaptation of advanced digital production (ADP) technologies	**Imports of advanced digital production technologies** (automated and/or with embedded digital systems) Selection of HS 2017 code 84-85-90, intersected with BEC 4 code 41-42	ALL	2002 – HS02 2017 – HS17	UNCOMTRADE
Export of ADP technologies	**Industrial competitiveness in advanced digital production (ADP) technologies**	**Export of digital production technologies** (automated and/or with embedded digital systems) Selection of HS 2017 code 84-85-90, intersected with BEC 4 code 41-42	ALL	2002 – HS02 2017 – HS17	UNCOMTRADE
Engagement with digital services		Import of **computer and information services** EBOPS 2002 code 7	77	2002 – HS02 2017 – HS17	UNCOMTRADE

Source: Authors

3.2 Methodology

Digital readiness is multidimensional. Adopting the entire set of indicators is recommended as the minimum foundation for countries aiming to assess their digital readiness. Each indicator captures a country's readiness across different foundational capabilities and I exposure to and imports of PTDP and ADP technologies. Countries should expect mixed performances across and within different foundational capabilities and levels of engagement with digital production technologies.

The benchmarking of performance also includes a country to gauge its foundational capabilities and level of exposure to PTDP and ADP compared with other countries and to assess the level of capabilities needed to be ready for digitalization. To determine whether a country's performance is adequate or whether it is lagging behind on the digitalization ladder, we propose three benchmarking approaches. Each of these can be used to conduct different types of benchmarking analysis, as outlined in Error! Reference source not found..

Box 7. Benchmarking tools and analysis

APPROACH 1: DIGITAL HEATMAP DASHBOARD (SHOWN IN SECTION 4)

- Assesses, visualizes and benchmarks a country's overall readiness to digitalize across the three sets of dimensions presented in the framework, namely
  - (i) enabling infrastructure,
  - (ii) productive capabilities and
  - (iii) innovation capabilities;
- Assesses, visualizes and benchmarks a country's overall readiness to digitalize in terms of previous exposure to and imports of PTDP and ADP technologies;
- Identifies specific capability gaps, i.e. the constraints in the country's foundational capabilities.

APPROACH 2: DIGITAL LADDER BENCHMARKING TOOL – CLOSE COMPARATORS

- Evaluates the progress of a given country in foundational capabilities over time and at different points in time compared to others within the same income group;
- Measures the level of effort needed, i.e. the steepness of the ladder, for the country to catch up with those at the top of the income group and which generally show a strong performance in digitalization.

APPROACH 3: DIGITAL LADDER BENCHMARKING TOOL – CLIMBING UP

- Measures the distance between a given country from others in different income groups that are generally more advanced in digitalization over time and at different points in time;
- Evaluates the level of effort needed, i.e. the steepness of the ladder, to catch up with countries in higher income country groups that are generally more advanced in digitalization.

Each of these benchmarking approaches compares countries based on the set of indicators introduced below and summarized in **Table 1** for foundational capabilities and in **Table 2** for digital capabilities. These comparisons can be thought of as countries moving along a digitalization ladder. A benchmarking analysis can be conducted by comparing a country against one or more countries that are on the same rung of the ladder or that have already progressed further up the ladder.

- One-to-one benchmarking

A one-to-one comparison can be conducted by comparing pairs of country performances in one or more indicators. Such comparisons are useful when a country wants to benchmark its digital readiness and performance against a specific country comparator identified by the government in its policymaking process.

- Benchmarking against close comparators (intra-group)

Governments often use countries within the same income groups as close comparators. Benchmarking against such close comparators can be achieved by comparing the country against all (or a selection of) countries within the same income group. We introduce two useful metrics in these comparisons.

- Average performance of close comparators:

The first metric is the average performance of a specific indicator within an income group. For example, a low-income country can compare its performance in digital connectivity (one of the indicators in **Table 2**) to the average level of digital connectivity in its own (low-income) country group.

- Steepness of the ladder

The second useful metric measures how countries within the same income group are from the country performing worst for a specific indicator to the country performing best within that group.

Box 8. Steepness of the digitalization ladder

The *steepness of the digitalization ladder* indicates a country's distance from foundational capabilities or its exposure to PTDP and ADP technologies, i.e. the level of effort needed to climb up the ladder. Steeper ladders require more effort. Steepness is measured as follows:

Intra-group ladder: $\frac{\textit{Value of the indicator for the top quintile}}{\textit{Value of the indicator for the lowest quintile}}$

Inter-group ladder: $\frac{\textit{Mean value of the indicator for UMICs}}{\textit{Mean value of the indicator for LICs}}$

- Benchmarking for climbing up the ladder (inter-group)

When formulating their 'climbing' strategies, governments often use countries in higher income groups as benchmarks for comparison. Benchmarking against higher-income group comparators can be conducted by comparing a country against all (or a selection of) countries within the higher income group. We introduce two useful metrics to conduct such comparisons.

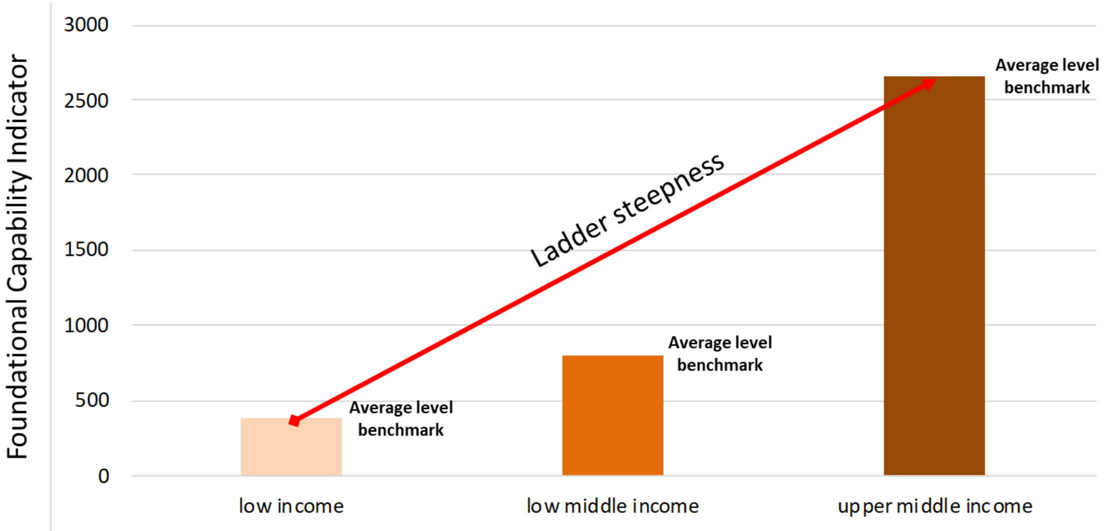
- Average performance of higher income groups

The first metric is the average performance for a specific indicator among a higher income group. A country aiming to catch up can compare its current performance against the average performance of countries in the higher income group.

3.3 Digital Readiness Ladder Benchmarking Tool

To construct the digital readiness ladder, the average value obtained for different country groups—low-income, low middle-income and upper middle-income (**Figure 7**)—is calculated. Each rung of the ladder represents the benchmark level for the countries in each group. We also calculate the steepness of the ladder based on these average value benchmarks (see Error! Reference source not found.).

Figure 7. Digital readiness ladder

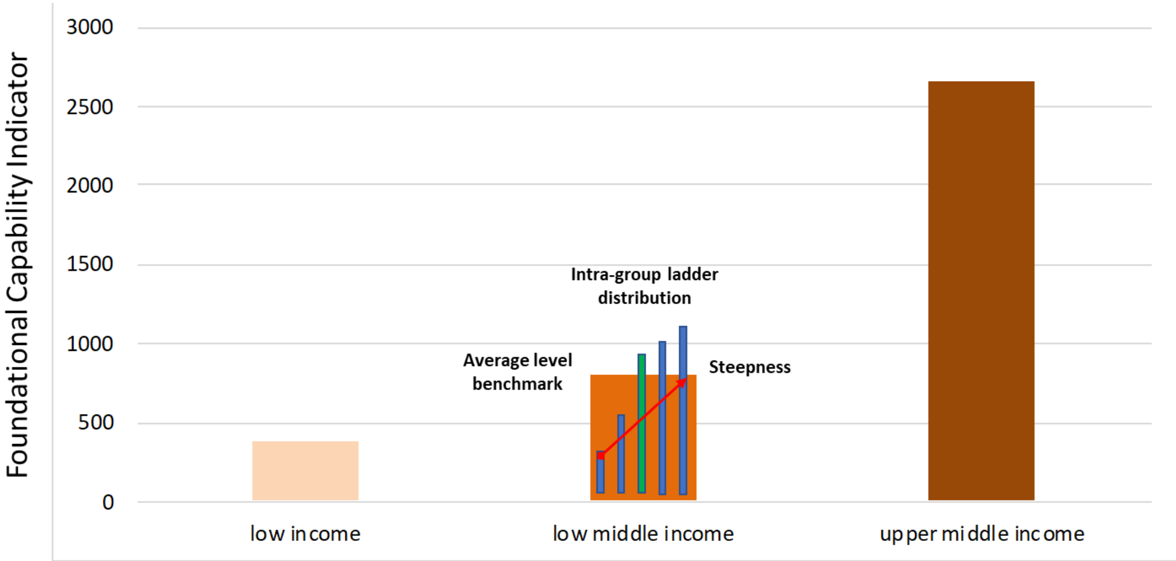


Source: Authors

Countries generally tend to perform around the average value of their respective country group. Countries should therefore first benchmark their performance against that of their closest comparators within the same country group. In some cases, the country may fall below the group's average, while in others, it may perform above that average. the distribution of countries for the given indicator can also be examined. Quintile distributions for each country group offer a means for intra-group performance analysis, including an assessment of intra-group steepness. This is achieved by dividing the values for an indicator into five equal groups. Each resulting group is called a quintile, with each quintile representing 1/5 or 20 per cent of the range of values for the indicator.

For a generic indicator, **Figure 8** illustrates the average value benchmark for the low middle-income (LMICs) group represented by the orange threshold. It also shows the distribution of performances across close country comparators within the same lower middle-income country (LMICs) group represented by the blue bars. Finally, it presents the steepness for a country in the LMICs group. The country represented by a green bar is selected as an example for analysis. This country's performance is above the average benchmark in the intra-country comparison (the green bar is above the orange threshold), but it is also far below the average level benchmark for the higher income comparator group of upper middle-income countries.

Figure 8. Digital readiness ladder – Close comparators



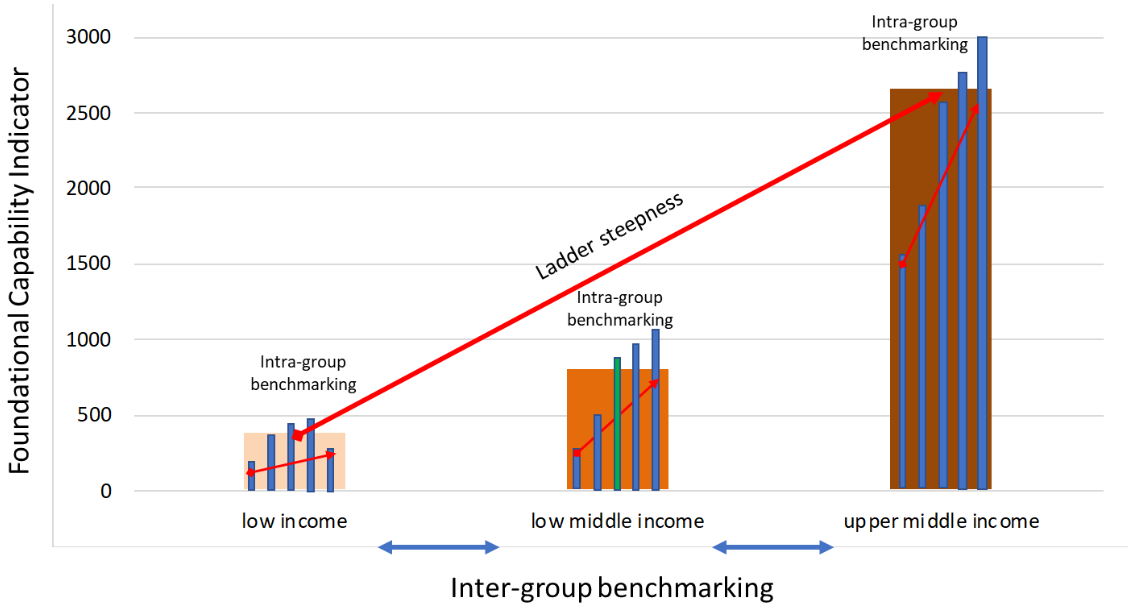
Source: Autors

Governments seeking to catch up and climb the digitalization ladder can benefit from using the Digital Readiness Ladder tool to conduct combined inter-group benchmarking analyses, i.e. focus on the next step of their journey. For instance, a low-income country can compare its performance against that of low middle-income countries and upper middle-income countries. In exceptional cases, a country may outperform (or underperform) in these inter-group comparisons. In other words, a low-income country may perform better than a low middle-income country, while an upper middle-income country may underperform relative to a low middle-income country. For indicators with a particularly steep ladder, that is, where the difference between the average performance of each country group is very high, advancing from the low-income to the upper middle-income country group may potentially take longer and require more learning and investment efforts.

To conduct an inter-group benchmarking exercise, the first step is to classify countries for which data are available into one of three categories, namely *low-income* (LICs), *lower middle-income* (LMICs) and *upper middle-income countries* (UMICs) based on the World Bank definition.[4] Next, the average value (i.e. mean) of each income group is computed using a specific point in time, and the distribution of each country selected within each income group is plotted. Both the intra- and inter-group steepness of the ladder can be calculated based on the average level benchmarks for each group. **Figure 9** shows that a given country, highlighted with the green bar, can benchmark its own performance within each country group. This allows the country to identify the most proximate comparators and set attainable targets by contrasting intra- and inter-group performance.

[4] https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

Figure 9. Digital readiness ladder: Climbing up



Source: Authors

Inter- and intra-group analyses along the digitalization ladder helps track countries' leapfrogging experiences and incremental improvements, respectively. Leapfrogging takes place when a country succeeds to climb up from its current country group performance to reach levels of performance comparable to a higher rung in the ladder. Incremental improvements represent a country's move from a lower to a higher quintile within the same country group.

Most of the indicators discussed below will further illustrate the use of the Digital Readiness Ladder Benchmarking tool. It analyses the digital readiness of a selection of countries at two different data points. The aim is to examine the high degree of heterogeneity in foundational capabilities across low-income countries (LICs), low middle-income countries (LMICs) and upper middle-income countries (UMICs). Two types of benchmarking analyses are presented for most indicators, including an estimation of the steepness of the ladder.

The analyses consider all LICs and middle-income countries. Among these, 20 countries were selected to illustrate differences in performance. The selection of countries considered their geographical variety and regional relevance.

3.4 Enabling infrastructure

The first layer of indicators considers the crucial role of enabling infrastructures as an essential precondition for adopting basic digital technologies. There are two main sets of indicators within this layer:

(i) energy, and

(ii) digital infrastructure.

3.4.1 *Energy infrastructure*

Indicator 1: Energy availability

This indicator measures the availability of electrical energy in a country. Large-scale electrical energy coverage is essential for digitalization, as most digital machines and equipment rely on continuous energy supply to operate properly. Industrialization and digitalization both depend on the availability of electricity.

Strategic questions:

- How much energy is available per capita?

Calculation: This indicator is measured by the amount of kWh per capita consumed in a given year and is calculated as:

$$\text{Energy availability} = \frac{Electric\ power\ consumption\ (kWh)}{Total\ population}$$

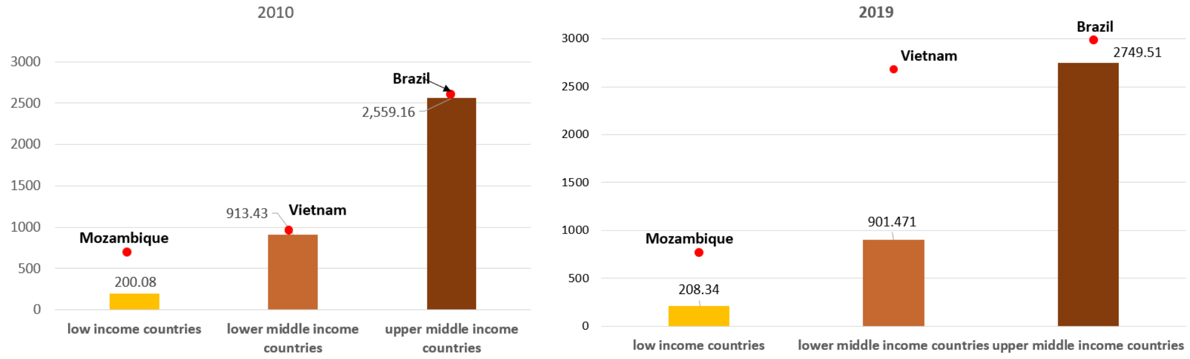
Variables required	Data source	Notes
Electric power consumption (kWh) Total population	World Development Indicators	Data available for 97 low- and middle-income countries (LMICs) for the 2005–2014 period

Please note: While the ideal measure is the amount of per capita electricity generated in a given year, data availability and coverage are much higher for electricity consumption, which is an adequate proxy.

Figure 10 presents the average of the three group categories in 2010 and 2019. The slope of the ladder is similar across the two points in time: the difference between LICs and LMICs intensified over time, with the difference between the two groups' averages widening in 2019. The last rung of the ladder, UMICs, is the highest and thus the most difficult to climb.

The case of Viet Nam is used as a case in point. As a rapidly industrializing nation, Viet Nam's growth in terms of per capita electricity consumption has been impressive, from just above the LMICs' average in 2010 to nearly the UMICs' average in 2019, thus being an outlier in the LMIC category. Similarly, Brazil moved from being just above the UMICs' average to positioning itself above the average of its group in 2019. By contrast, Mozambique maintained a consistent position within its group over time but its position in terms of absolute value weakened. This is expected, as countries in the bottom of the distribution face significant challenges in developing and jumping from one group to the next.

Figure 10. Electricity per capita by income group, 2010–2019



Steepness: 12.7

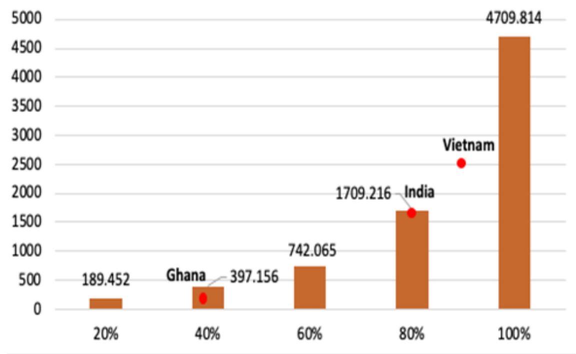
Steepness: 13.1

Note: Numbers in graph refer to height of bars.

How is the country performing relative to its closest comparators? Intra-group benchmarking

The analysis is presented in **Figure 11** to **Figure 13**, which illustrate the intra-group ladders. Each of these ladders reveal where countries stand, and what their progression could look like. The level of steepness tends to decrease with increases in income per capita; as countries start consuming more electricity, their differences tend to flatten.

Figure 11. Availability of electricity in LICs: Intra-group ladder (quintiles)

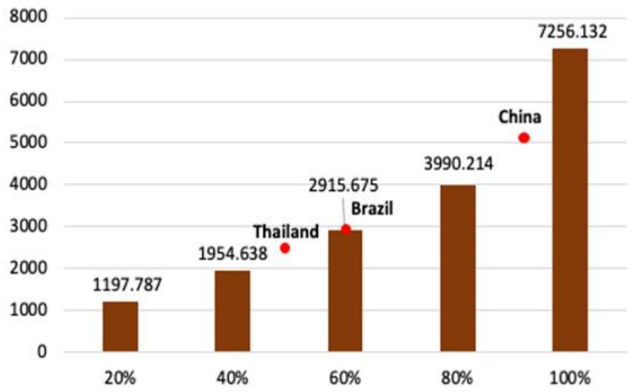


Steepness: 79

Note: Numbers in graph refer to height of bars.

Figure 11 shows the highest steepness level. In the case of LICs, the distribution of countries in the initial three quintiles is quite even. The greatest difference is observable in the last quintile. The "jump" is particularly challenging between the fourth and the fifth quintile. Mozambique is an example of a country that leaped from the fourth to the fifth quintile of the distribution.

Figure 12. Availability of electricity in LMICs: Intra-group ladder (quintiles)

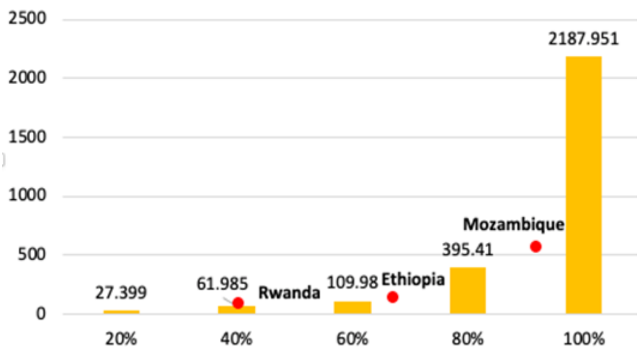


A similar conclusion can be drawn for the LMICs' ladder **(Figure 12**), although with a lower steepness and a better distribution among the different bars. In this group, some of the top-performing countries in the last quintile appear to have widened the gap to the rest of the distribution.

Steepness: 24.8

Note: Numbers in graph refer to height of bars.

Figure 13. Availability of electricity in UMICs: Intra-group ladder (quintiles)



The graph of UMICs is the least steep (**Figure 13**). This is consistent with the notion that countries' development trajectory becomes more paved as they enter this group. Differences in per capita electricity consumption narrow. China is reaching the distribution's top quintile, a sign of its rapid development trajectory.

Steepness: 6.05

Note: Numbers in graph refer to height of bars.

Indicator 2: Energy reliability

This indicator conveys the reliability of a country's electrical energy network by measuring the frequency of power outages. For digitalization to be beneficial, electrical energy must be both widespread and reliable.

Strategic questions:

- How reliable is the country's electricity supply?

Calculation: This indicator is measured by the percentage of firms experiencing electrical power outages in the country during the previous fiscal year and is calculated as:

$$\text{Energy reliability} = \frac{\textit{Firms experiencing electrical outages}}{\textit{Total number of firms}}$$

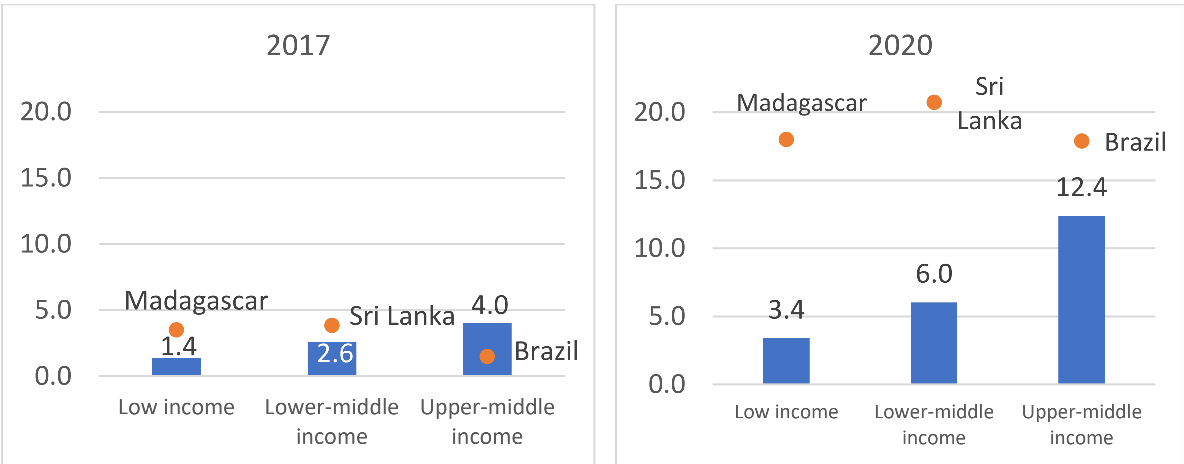
Variables required	Data source	Notes
Firms experiencing electrical outages Number of firms in the survey	The World Bank Enterprise Survey	Data available for 114 LMICs for the year 2017

Please note: It would be ideal to use the number of productive hours lost by each establishment. These data do not differentiate between a firm that experiences two hours of electrical outage, for example, to two days of outages. Unfortunately, such detail on the number of productive hours lost is not collected as part of the World Bank Enterprise Survey.

Progress in digitalization requires not only extensive connectivity, it must also be fast and reliable. This indicator proxies the quality of connectivity based on the country's mean download speed.

The data show a significant increase in internet speed across all income groups, especially in UMICs, where the average value rose from 4.0 Mbps to 12.4 Mbps (**Figure 14**). The ladder for LICs has become steeper, which calls for increased efforts to improve connectivity infrastructure. Several countries reported major leaps in this indicator during the short period of analysis (**Figure 14**). In the case of LMICs, some examples include Madagascar (from 3.5 to 18.00), Sri Lanka (from 3.8 to 20.7) and Brazil (from 1.5 to 17.9). Other examples include Malaysia's impressive jump (from 6.7 to 46.8), and the smaller jumps of India (from 2.1 to 12.5), Bulgaria (from 17.5 to 46.2) and Moldova (from 10.7 to 27.5).

Figure 14. Mean download speed, by income group, 2017–2020

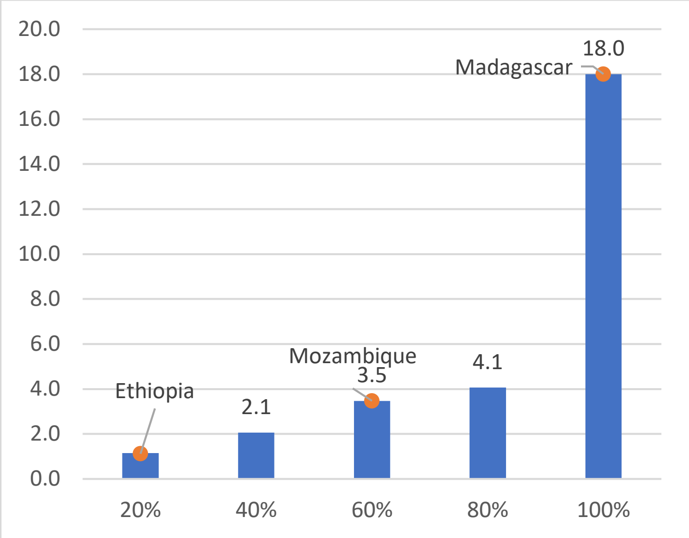


Steepness: 2.9 **Steepness: 3.7**

Note: Numbers in graph refer to height of bars.

This finding suggests that this indicator is not very steep, allowing for big jumps, even in less developed countries. The intra-group ladders reveal that the level of steepness is similar across all income levels. Some skewing is observable in all income groups, however, with the values of the last quintile being significantly higher than the lower quintiles. Hence, only few countries in each income group have a significantly more developed internet connectivity infrastructure.

Figure 15. Mean download speed in low-income countries – Intra-group ladder

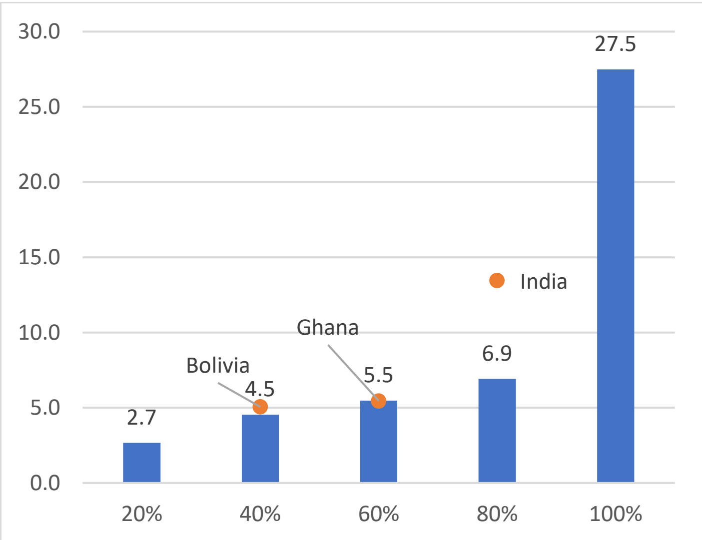


In the LICs group (**Figure 15**), Madagascar skews the distribution with its mean internet speed of 18.0 Mbps, while other LICs have much slower speeds, such as Mozambique (3.5), and Ethiopia (1.1).

Steepness: 15.7

Note: Numbers in graph refer to height of bars.

Figure 16. Mean download speed in lower middle-income countries – Intra-group ladder (quintiles)

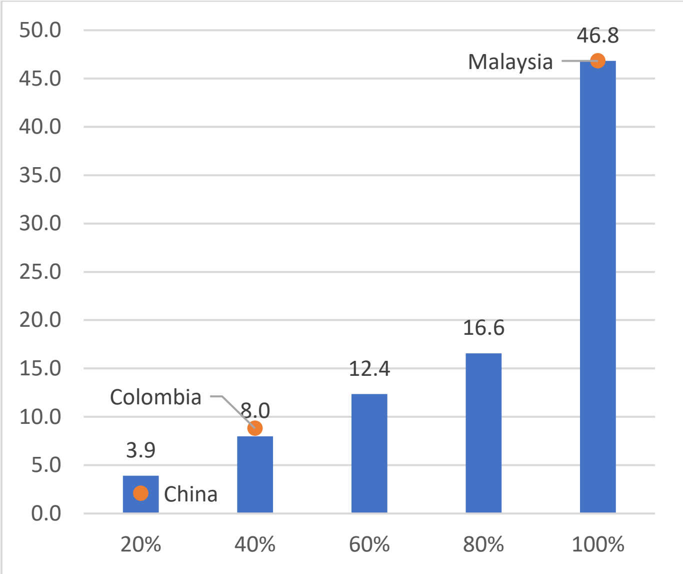


In the LMICs group (**Figure 16**), those countries that skew the distribution are Moldova (27.5), Sri Lanka (20.7), Ukraine (15.1), with India (13.5) and Viet Nam (13.4) following closely behind. On the long tail, we find much slower internet speeds, such as in Bolivia (5.1) and Ghana (5.5).

Steepness: 10.3

Note: Numbers in graph refer to height of bars.

Figure 17. Mean download speed in upper middle-income countries – Intra-group ladder (quintiles)



Steepness: 12.0

Note: Numbers in graph refer to height of bars.

In the UMICs group (**Figure 17**), Malaysia tops the distribution with 46.8 Mbps mean internet speed. This group also includes countries with very low values, such as Colombia (8.8) and, surprisingly, China (2.1).

3.4.2 Digital infrastructure

Indicator 3: Digital connectivity

This indicator measures access to broadband connectivity in the country. An intensification of digitalization requires widespread access to wired broadband internet connectivity as an essential enabling factor.

Strategic questions:

- How widespread is the use of broadband internet?

Calculation: This indicator is measured by the number of fixed broadband subscriptions per 100 population in the country and is calculated as:

$$\text{Digital connectivity (wired)} = \frac{Fixed\ broadband\ subscriptions}{100\ population}$$

Variables required	**Data source**	**Notes**
Firms experiencing electrical outages Number of firms in the survey	The International Telecommunication Union (ITU), World Telecommunication/ICT Indicators Database, via World Bank	Data available for 130 LMICs for the 2003–2019 period

Indicator 4: Quality of connectivity

This indicator measures the quality of the country's internet connectivity. Digital technologies, especially the more advanced ones (IoT, AI, cyber-physical systems) require high-speed, low-latency, reliable internet connectivity. The indicator is measured by the mean download in megabits per second; it is a measure of internet bandwidth, which represents the download rate of a given internet connection.

Strategic questions:

- How fast is the internet speed?

Calculation: The quality of connectivity is calculated as:

Quality of connectivity $= Mean\ download\ speed$

Variables required	Data source	Notes
Firms experiencing electrical outages Number of firms in the survey	M-Lab's 2.0 platform, via cable.co.uk/broadband/speed	Data available for the period 2017–2020

Please note: The annual availability of data is quite limited; therefore, it is difficult to establish a country's trajectory in terms upgrading its internet bandwidth.

3.5 Production capabilities

The second layer considers the critical role production capabilities play for a country's engagement with digital production technologies. There are two main set of indicators within this layer. First, **basic** production capabilities which create the necessary conditions to invest in new technologies. Second, **intermediate** production capabilities which proxy the organizational capabilities that are key for creating micro-efficiency and a proper deployment of new digital production technologies.

3.5.1 Basic production capabilities

Indicator 5: Productive investments

Building up pre-existing capabilities needed to engage with higher levels of sophistication involves higher investments in plants, machinery, equipment, etc. Economists capture this through gross fixed capital formation (GFCF). The share of investments relative to manufacturing in total GFCF is a proxy for investments for upgrading the manufacturing structure, such as the establishment of a new plant, the purchase of new production lines, machinery and equipment. The aim is to capture specific investments in production technologies (see Error! Reference source not found.).

Box 9. Manufacturing GFCF as % of total GFCF

Strategic questions:

- What is the share of manufacturing investments in the country's total investments?

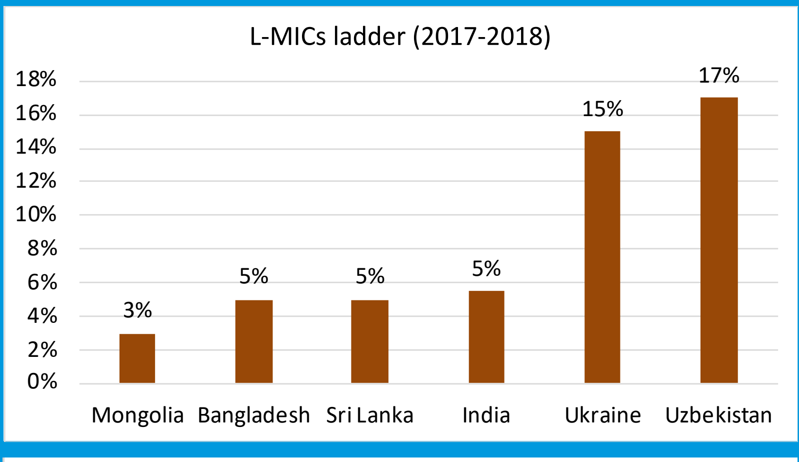
Calculation: Productive investments in manufacturing are calculated as:

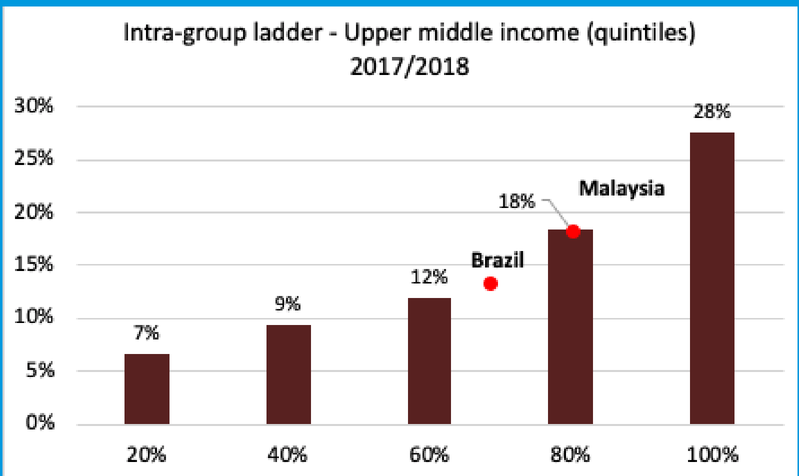
$$\text{Productive investments} = \frac{\textit{Manufacturing GFCF}}{\textit{Total GFCG}}$$

Variables required	Data source	Notes
Manufacturing gross fixed capital formation Total gross fixed capital formation	UNIDO's INDSTAT World Development Indicators	Data are available for 39 LMICs for the 2010–2018 period

This indicator identifies investments targeted at upgrading a country's manufacturing structure relative to its total productive structure. Due to lack of data availability, the computation of this indicator is only possible for a limited set of countries. Error! Reference source not found. presents available data for six LMICs and a distribution for UMICs.

Figure 18. Manufacturing GFCF as % of total GFCF





Note: Numbers in graph refer to height of bars.

We resort to a proxy for productive investments by looking at the aggregate GFCF relative to GDP, which is an indication of the country's efforts to expand the entire economy's productive capacity. This is illustrated in Error! Reference source not found., which presents data for 2012 and 2018.

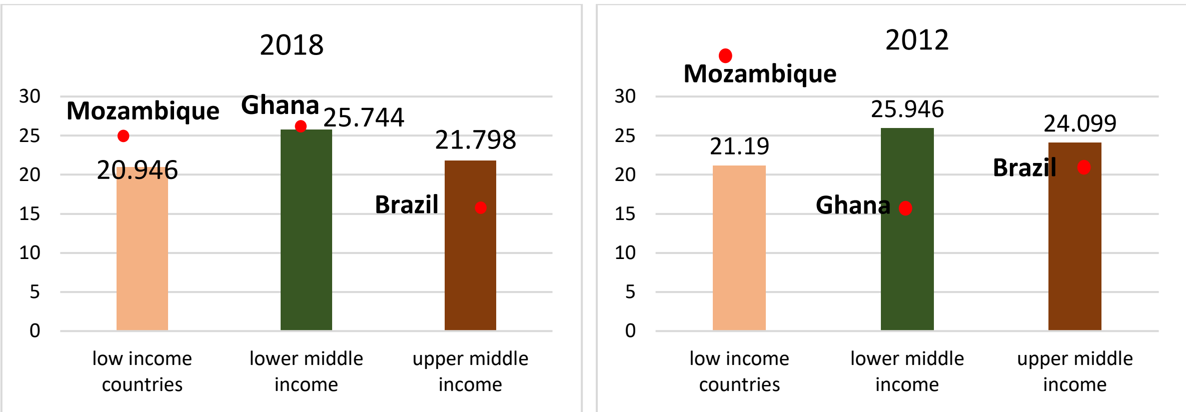
Calculation: Productive investments are calculated as:

$$\text{Productive investments} = \frac{Total\ GFCF}{GDP}$$

Variables required	Data source	Notes
Total gross fixed capital formation as share of GDP	World Bank national accounts data, and OECD National Accounts data files	Indicator is computed at the source

The indicator GFCF as a share of GDP reveals that within the LMICs' intra-group ladders, LMICs' bars are higher than UMICs, despite the latter's higher income level. This difference increases over time, with both the LMICs and UMICs' group values slightly decreasing over time. This could be related to 'premature industrialization', which has characterized many LMICs in the last 5–10 years. Moreover, high GFCF investment levels are typical of countries that are heavily industrializing. Another explanation could be that once countries reach a sustained level of investment, it becomes quantitatively less but qualitatively stable or higher (which is information we do not show). The steepness is low in both graphs, and decreases in 2018, thus indicating that LICs may be quickly catching up.

Figure 19. GFCF % of GDP by income group, 2012–2018



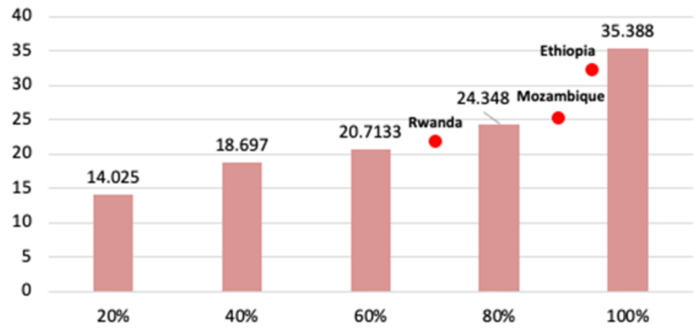
Steepness: 1.13

Steepness: 1.04

Note: Numbers in graph refer to height of bars.

When looking at how countries change over time, we find that Mozambique performed well at both points in time, although its share of GFCF in GDP was much higher than the LICs' mean, while in 2018, it came closer to the country group's average. Ghana's share improved, almost reaching its country group mean. Similarly, although with a reverse trend, Brazil's position worsened vis-á-vis other UMICs in the same group. Steepness levels associated with GFCF as a share of GDP are less pronounced across the different income groups (**Figure 20**, **Figure 21** and **Figure 22**).

Figure 20. GFCF % of GDP -ow-income countries – Intra-group ladder (quartiles)

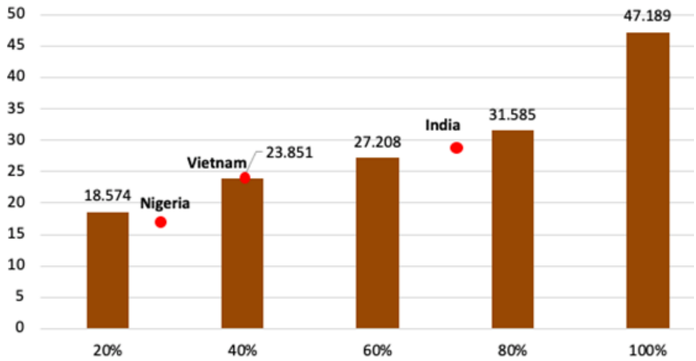


Steepness: 2.5

Note: Numbers in graph refer to height of bars.

Figure 20 shows that LICs have the same 2.5 steepness level as LMICs. Behind minor changes (decimal points!) lie important structural change dynamics that are difficult to grasp. Mozambique and Ethiopia are close to the top quintile of their group, while Rwanda slightly lags behind.

Figure 21. GFCF % of GDP in lower middle-income countries – Intra-group ladder (quartiles)

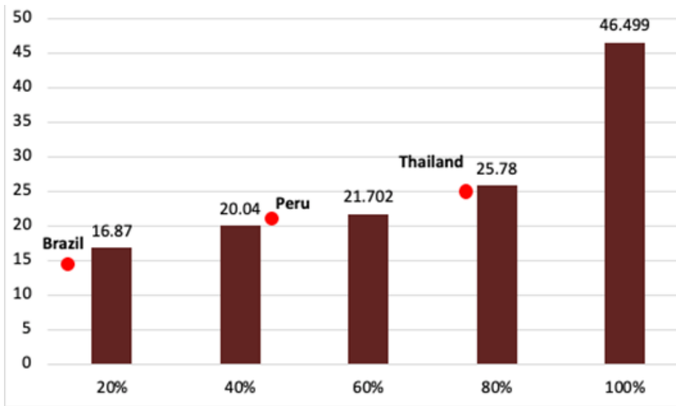


Steepness: 2.5

Note: Numbers in graph refer to height of bars.

Figure 21 shows that the distribution of GFCF as a share of GDP is relatively even in LMICs, although it is steeper in the last quintile. Rapidly industrializing countries such as Viet Nam and India still have room for improvement to reach higher levels of investments. Nigeria has a low share of GFCF % of GDP, most likely due to its concentration in oil extraction which is associated with lower levels of industrialization.

Figure 22. GFCF % of GDP in upper middle-income countries – Intra-group ladder (quartiles)



Steepness: 2.7

Note: Numbers in graph refer to height of bars.

The steepness level is more evident for UMICs (**Figure 22**). The gap between the fourth and fifth quintiles is particularly wide. China, whose value corresponds to the last quintile, is an outlier and skews the distribution to the top quintile. Brazil has a surprisingly low value of GFCF % of GDP.

Indicator 6: Productive skills

This indicator measures the mean years of schooling, providing a quantitative picture of the average number of years people spend in school. The indicator is measured as the average number of completed years of education of a country's population aged 25 years and older, excluding years spent repeating individual grades.

Strategic questions:

- How many years do people spend in school on average?

Calculation: Mean years of schooling (productive skills) are calculated as:

$$\text{Productive skills} = \frac{\textit{Years of schooling completed by the population}}{\textit{Total population}}$$

Variables required	Data source	Notes
Mean years of schooling	UNESCO	Data are available for 39 LMICs for the period 2014–2019

Please note: While this basic indicator fails to distinguish between grade and type of school, it must be considered due to the high relatedness that exists between education and the development of production capabilities.

3.5.2 Intermediate production capabilities

Indicator 7: Operational efficiency

ISO 9001 is the international standard that specifies the requirements for a quality management system, which only firms that possess solid productive and organizational capabilities can obtain. It is a key requirement for access to international customers with high quality standards. This indicator is measured by taking the number of ISO 9001 certificates per 1,000 population.

Strategic questions:

- How many years do people spend in school on average?

Calculation: Number of ISO certificates (operational efficiency) is calculated as:

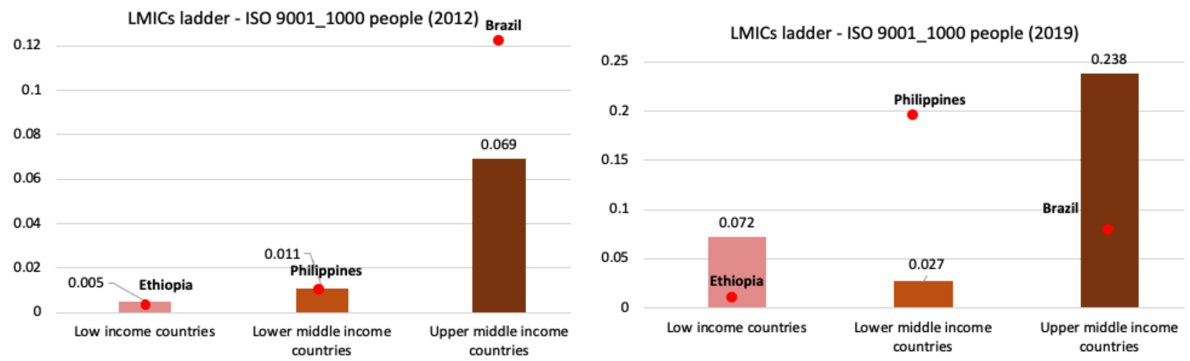
$$\text{Operational efficiency} = \frac{\textit{Number of ISO } 9001 \textit{ certificates}}{1{,}000 \textit{ population}}$$

Variables required	Data source	Notes
Number of ISO 9001 certificates Population	ISO	This indicator shows an estimation of the number of valid certificates at the end for the last available year. It is available for 116 LMICs

Please note: The major limitation is that this indicator only looks at the best firms within each country without considering other firms in the same country that have not yet obtained the certificate. It is an excellent proxy of firms' organizational capabilities.

If the investment in GFCF is an essential step towards capital accumulation and industrialization, the next level of analysis is represented by an indicator that captures a certain degree of firms' organizational capabilities. The number of ISO 9001 certificates (measured for 1,000 population) is such an indicator, as it provides information on how many firms can meet an internationally recognized quality management standard. **Figure 23** presents the indicator for 2012 and 2019, disaggregating it into the three LMICs groups. The steepness decreased significantly over time; however, it is important to note that this indicator presents a very high degree of heterogeneity: first, LICs and UMICs' position improved over time, with both groups showing a strong upward trend of their average values. Conversely, the average value for LMICs increased over time, but much weaker in comparison to the other two groups, with their average value for 2019 being lower than LICs'.

Figure 23. ISO 9001 per 1,000 people by income group, 2012–2019



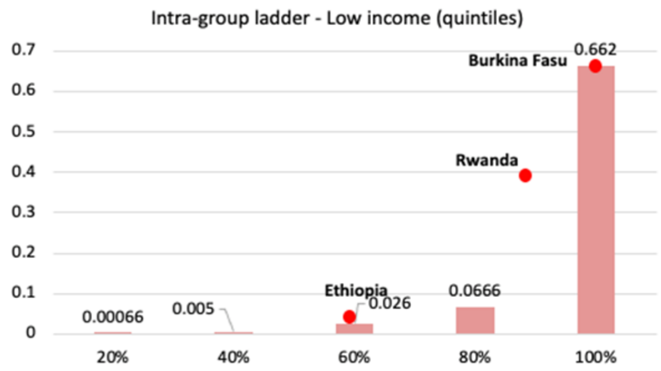
Steepness: 13.8

Steepness: 3.3

Note: Numbers in graph refer to height of bars.

Countries show very different patterns. For example, Ethiopia nearly reached the average value of its group in 2012 but could not keep up with the rest of LICs and trailed at the bottom of its group in 2019. Similarly, Brazil showed an exceptional performance in 2012, while its position deteriorated both in absolute terms and in comparison with other countries in its group. On the other hand, The Philippines was in line with its group in 2012, but was an outlier in 2019 after significantly improving its position.

Figure 24. ISO 9001 per 1,000 people, low-income countries – Intra-group ladder (quintiles)

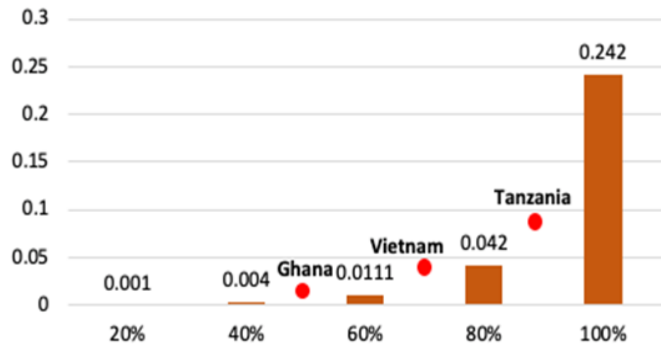


Steepness: 1,103.3

Note: Numbers in graph refer to height of bars.

LICs' steepness is particularly high (**Figure 24**). The gap between the fourth and fifth quintile appears particularly challenging. Rwanda seems to be approaching the last quintile. Burkina Faso shows a strong performance and holds the top position in its group, while Ethiopia is at 60 per cent of the distribution, which is consistent with the group's average value.

Figure 25. ISO 9001 per 1,000 people, lower middle-income countries – Intra-group ladder (quintiles)

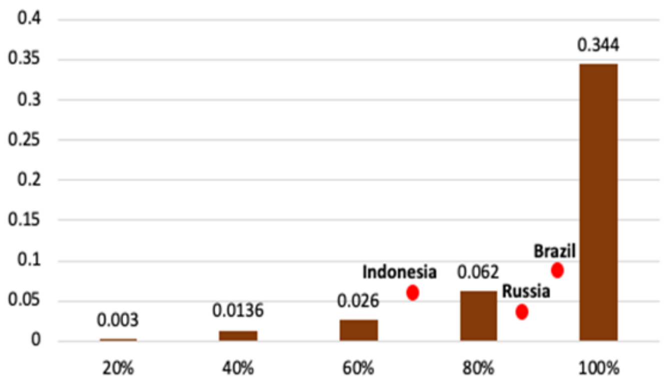


Steepness: 242

Note: Numbers in graph refer to height of bars.

The situation is similar for LMICs (**Figure** 25), with a wide gap between the last two quintiles, although the overall steepness is lower than for LICs. Countries that are rapidly industrializing, such as Viet Nam and Tanzania, have higher values compared to the group average. Countries at the top of the distribution, e.g. Mexico and Costa Rica, have high-value manufacturing sectors that have been developing over the last decade.

Figure 26. ISO 9001 per 1,000 people, upper middle-income countries – Intra-group ladder (quintiles)



Steepness: 114.6

Note: Numbers in graph refer to height of bars.

UMICs show the lowest steepness among LMICs (**Figure 26**). However, the distribution for this group is also skewed, as the gap between the fourth and fifth quintile is particularly high.

Indicator 8: Technology absorption

This indicator captures the extent to which firms' production processes use technologies developed abroad, which is a useful proxy for firms' level of technological capabilities. The indicator is measured by taking the charges incurred for the use of intellectual property—payments in current US$—adjusting them to GDP to allow for comparisons across countries, while taking differences in the size of their economies into account. Alternative indicators that also measure aspects of technology absorption are discussed in EQuIP Tools 2, 3, 4 and 9.

Strategic questions:

- How much technology is absorbed by domestic firms?

Calculation: Technology absorption is calculated as:

$$\text{Technology absorption} = \frac{\textit{Charges for the use of intellectual property}}{\textit{GDP}}$$

Variables required	Data source	Notes
Charges for the use of intellectual property	International Monetary Fund, Balance of Payment Statistics	The indicator is available for 84 LMICs and for the period 1976–2019
Gross domestic product	World Bank	

Please note: While this indicator is a useful proxy of technology absorption, especially considering that most low- and lower middle-income countries rely on imports and the use of foreign technology to upgrade their productive capabilities, it does not consider the development of indigenous technology and the use thereof.

3.6 Innovation capabilities

The third layer considers the crucial role innovation capabilities play for the engagement with digital production technologies. There are two main sets of indicators within this layer. First, **basic efforts** in developing innovation capabilities that create the necessary conditions to invest in new technologies and to adapt them to local conditions. Secondly, efforts to develop **intermediate outputs** from innovation capabilities.

3.6.1 Basic: Innovation effort

Indicator 9: Advanced skills

This indicator captures the population's participation rate in tertiary education of a country. Its relevance for digitalization lies in the fact that a broad base of university-level knowledge is needed for the absorption, diffusion and development of advanced digital technologies. This includes not only technical skills, but also knowledge in business management, foreign languages, laws and regulations, etc.

The indicator is measured by the gross enrolment ratio of the official school age population for tertiary education (both sexes). This is calculated by the number of students enrolled in tertiary education, expressed as a percentage of the population of the official age for tertiary education (the 5-year age group immediately following upper secondary education).

Strategic questions:

- What is the share of highly educated people in the country?

Calculation: Advanced skills are calculated as:

Advanced skills ($gross\ enrolment\ ratio\ in\ tertiary\ education$)

$$= \frac{Number\ of\ students\ enrolled\ in\ tertiary\ education}{Population\ in\ the\ 5-year\ age\ group\ immediately\ following\ upper\ secondary\ education}$$

Variables required	Data source	Notes
Number of students enrolled in tertiary education Population in the 5-year age group immediately following upper secondary education	UI UIS	The data are available for 74 LMICs for the 2014–2019 period

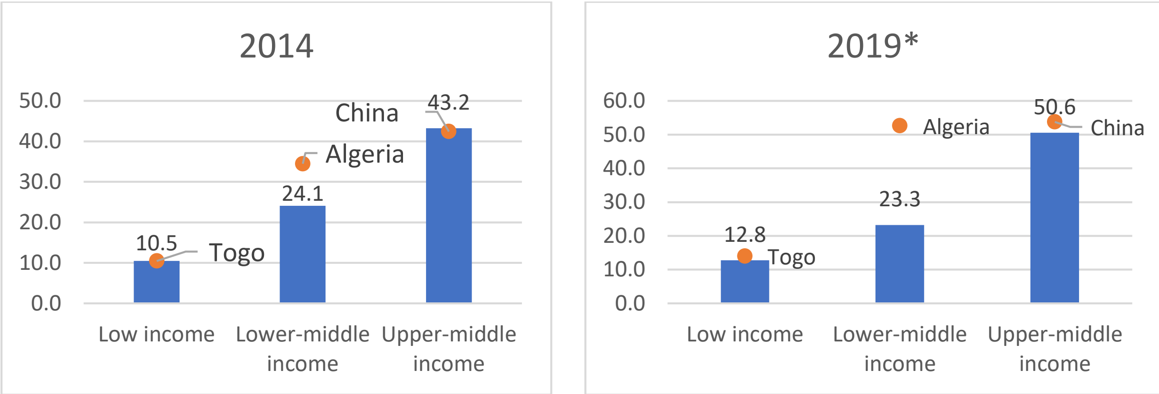
Please note: This is the gross enrolment ratio, which counts the total number of students enrolled in tertiary education. It includes overaged students, e.g. due to repetition of grades or other inefficiencies in the education system. The gross ratio thus measures the overall level of participation in tertiary education of students of all ages, and not the education system's 'efficiency' in educating students at the appropriate age.

This indicator measures the number of persons enrolled in tertiary education as a share of the total number of people in the appropriate age range for tertiary education (in most countries, 18–22 years old). This indicator reflects the level of development of advanced skills within a country's population, which are key for fostering innovation and digitalization.

In the LMICs ladder, we observe a consistent distribution, with the mean value of LMICs roughly twice that of LICs, and the mean value of UMICs representing roughly twice the value of LMICs. This share remains stable over time. Notably, the steepness of the ladder remains unchanged from 2014 to 2019.

Figure 27 depicts countries that successfully upgraded their ratios considerably in the short period of 2014–2019. These are Togo (from 10.5 to 14.0), Algeria (from 34.5 to 52.6), and China (from 42.4 to 53.8). Another impressive case of success is Georgia, increasing its ratio from 42.2 to 63.9. Countries that experienced declines are Albania (from 65.8 to 59.7), Benin (from 15.9 to 12.5), Tunisia (35.3 to 31.8) and Rwanda (from 7.4 to 6.2).

Figure 27. Gross enrolment ratio in tertiary education by income group, 2014–2019



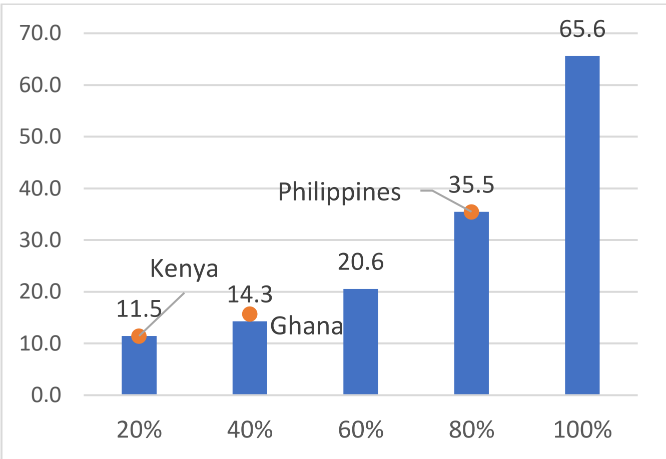
Steepness: 4.1

Steepness: 4.0

Note: Numbers in graph refer to height of bars.

In the intra-group ladders, we observe that the steepness tends to diminish as countries' income increases. This suggests that this indicator is based on 'cumulative causation', i.e. the more it is developed, the easier it becomes to develop it still further.

Figure 28. Intra-group ladder – Lower-middle-income countries (quintiles)

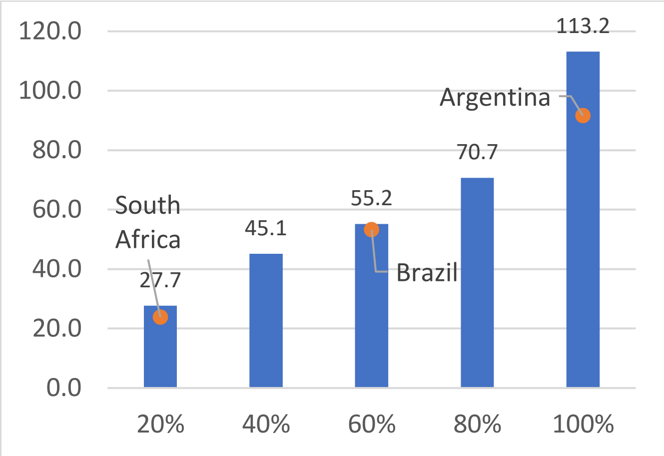


In the LMICs group (**Figure 28**), we find a large range of countries. From countries with very low ratios such as Kenya (11.5) and Ghana (15.7), to countries with higher ratios such as The Philippines (35.5), Algeria (51.4) and Mongolia (65.6).

Steepness: 5.7

Note: Numbers in graph refer to height of bars.

Figure 29. Intra-group ladder – Upper middle-income countries (quintiles)



Steepness 4.1

Note: Numbers in graph refer to height of bars.

In the UMICs group (**Figure 29**), most countries show a high ratio of enrolment in tertiary education, but some countries are lagging behind, such as South Africa (23.8). Brazil, despite its high income per capita, continues to have a relatively low ratio (53.3). Argentina builds on its longstanding tradition of education and boasts a ratio of 91.6.

Indicator 10: Specialized skills

This indicator measures the level of specialization of a country's tertiary education system to the specific skills needed for digitalization, namely science, technology, engineering and mathematics (STEM). Although digitalization requires a high level of skills across many different areas, these are the core specialized skills required, which are usually in short supply in the world. This indicator is measured by the percentage of STEM graduates in tertiary education.

Strategic questions:

- What is the share of graduates from STEM programmes in the country?

Calculation: Specialized skills are calculated as:

Specialized skills = $Percentage\ of\ graduates\ from\ STEM\ programmes\ in\ tertiary\ education, both\ sexes$

$$= \frac{Graduates\ from\ STEM\ programmes}{Total\ graduates}$$

Variables required	Data source	Notes
Graduates from STEM programmes Total graduates	UNESCO UIS	Data are available for 50 LMICs for the 2014–2019 period

Please note: This indicator measures the percentage of STEM graduates in total graduates. This means that the indicator calculates the specialization of the country's tertiary education in STEM areas, not the total number of STEM graduates in the given country. Caution should be taken when using this indicator for countries with a small number of total graduates (small tertiary education sector).

Indicator 11: Research effort

This indicator measures a country's total R&D effort. A large investment in R&D indicates the existence of capabilities to carry out research and innovation, which are crucial for digitalization. This indicator is measured by gross expenditure in R&D (public and private) as a share of GDP.

Strategic questions:

- How much is spent on R&D in the country?

Calculation: Research effort is calculated as:

Research effort = $\frac{Gross\ expenditure\ in\ R\&D}{GDP}$

Variables required	Data source	Notes
Gross expenditure in research and development Gross domestic product	UNESCO UIS	Available for 48 LMICs for the 2013–2018 period

Please note: This indicator only measures the country's research effort. It does not take the outcomes of this effort, nor its quality, into account.

Gross expenditure in R&D as a share of GDP is an indicator of a country's research effort. It measures both public and private investments in R&D and compares the to the size of the country's economy (GDP). While innovation may also take place without R&D, modern industries increasingly require dedicated labs and facilities for the development of new technologies, components and products. Thus, it is a useful indicator of a country's overall innovativeness.

Figure 30 shows that this indicator is relatively stable in terms of the three income groups' mean values in 2013 and 2018. The biggest change was the **reduction** of the LIC group's mean value, which fell from 0.36 to 0.25. This suggests that LMICs, on average, did not invest more in R&D 2018 than they did in 2013, despite the fact that the ladder is not particularly steep.

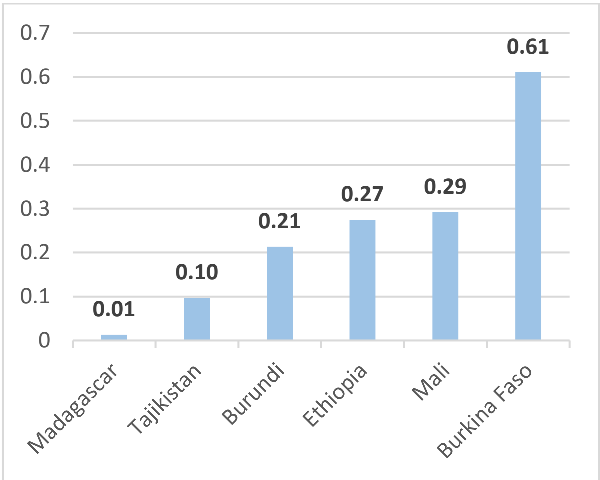
Two countries were able to significantly increase their investment in R&D: Viet Nam (a LMIC) and Thailand (a UMIC). Viet Nam's level of investment rose from 0.37 per cent of its GDP in 2013 to 0.53 per cent in 2018. Thailand more than doubled its investment in R&D as a share of GDP, which grew from 0.44 to 1.00 per cent in 2018. One example of a country that witnessed a regression in this indicator is Ethiopia (a LIC), which invested 0.60 per cent of its GDP in R&D in 2013, but only 0.27 per cent in 2018.

Figure 30. GERD as % of GDP by income group, 2013–2018

Steepness: 1.4 **Steepness: 2.2**

Note: Numbers in graph refer to height of bars.

Figure 31. GERD as % of GDP in upper middle-income countries – Intra-group ladder (quintiles)

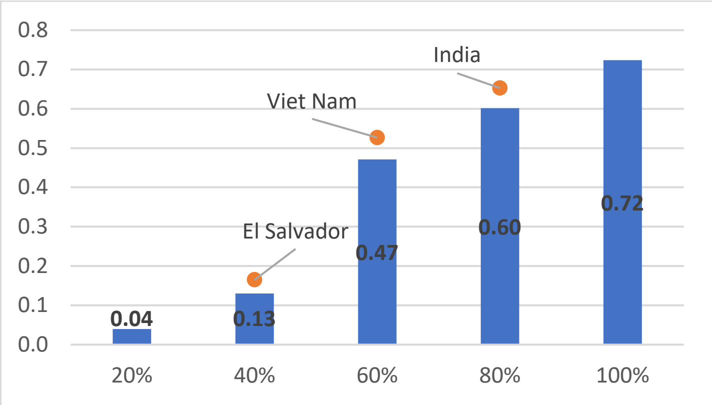


In the intra-group ladders (**Figure 31**), the steepness interestingly tends to diminish as the countries' income increases, with values of 47.9 (LICs), 18.1 (LMICs), and 11.6 (UMICs). This seems less applicable to the very high last quintile, and is more likely attributable to a very low first quintile in the LICs and LMICs groups. This points to a possible 'cumulative causation' process for this indicator – the more is invested in it, the easier it becomes to invest more in it.

Steepness: 47.9

Note: Numbers in graph refer to height of bars.

Figure 32. GERD as % of GDP, lower middle-income countries – Intra-group ladder (quintiles)

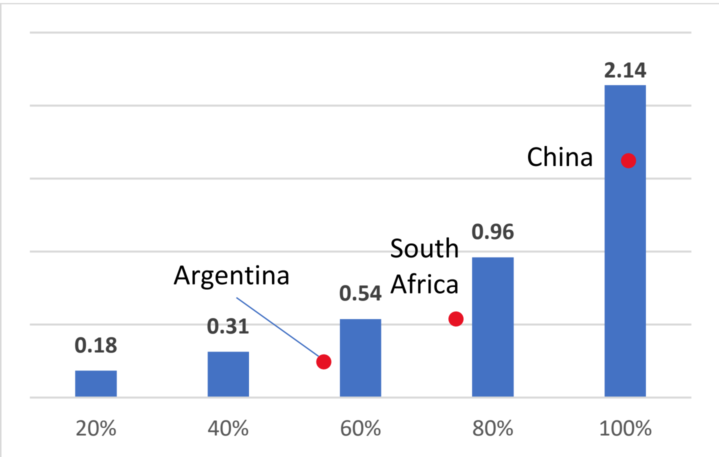


In the LICs group (**Figure 32**), Madagascar has virtually no R&D activities, while Burkina Faso has the highest value (0.61). In the LMICs group, two countries invest over 0.5 per cent of their GDP in R&D – Viet Nam and India. In this group, a country that invests very little is El Salvador (0.16).

Steepness: 18.1

Note: Numbers in graph refer to height of bars.

Figure 33. GERD as % of GDP, –upper middle-income countries – Intra-group ladder (quintiles)



In the UMICs group (

Figure 33), China is by a large margin the most innovative country with a value of 2.14 (with Brazil ranking second with a value of 1.16). South Africa (0.83) and Argentina (0.49) fall below the 1 per cent mark.

Steepness: 11.6

Note: Numbers in graph refer to height of bars.

3.6.2 Intermediate: Innovation output

Indicator 12: Research output

This indicator measures the production of academic articles by the country's scientists and technicians. It captures the quality of the research conducted in the country, which can have an important impact on digitalization both directly through research in areas related to digital technologies, or indirectly by creating innovation capabilities. This indicator is measured by the number of scientific and technical journal articles per million people.

Strategic questions:

- How much academic research is produced in the country?

Calculation: Research output is calculated as:

Research output = $\frac{Number\ of\ scientific\ and\ technical\ journal\ articles\ published}{Total\ population} \times 1\ million$

Variables required	Data source	Notes
Number of scientific and technical journal articles published Total population	National Science Foundation, Science and Engineering Indicators, accessed via World Bank	Data are available for 133 LMICs for the 2000–2018 period

Please note: This indicator measures the number of scientific and technical articles published, but it does not account for the quality of these articles. The research fields considered are: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.

Indicator 13: Innovation output (patents)

This indicator measures a country's innovation output potential based on the number of patents in force in the country, i.e. the patents granted to both domestic and foreign firms established in the country. Patents are a common measure of a country's level of innovativeness, as it is the formal way of protecting innovations. A high number of patents in a country thus indicates a high level of innovation capabilities, which are essential for absorbing and developing digital technologies. This indicator is measured by the total number of patents in force per USD 100 billion GDP.

Strategic questions:

- How many patents were registered in the country?

Calculation: Innovation output (in terms of patents) is calculated as:

Innovation output (patents) = $\frac{Total\ patents\ in\ force}{GDP} \times 100\ billion$

Variables required	Data source	Notes
Total patents in force Gross domestic product	WIPO database	Data available for 123 LMICs for the 2004–2019 period

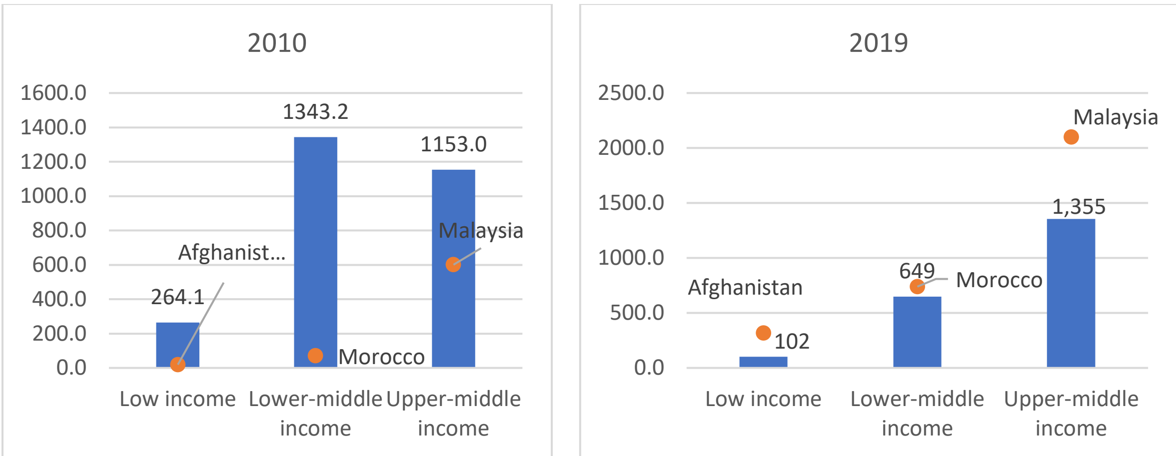
Please note: There are many well-known caveats in using patent data. For example, there are many ways of protecting an innovation (trade secret, lead-time, complexity, etc.), whereby patenting is just one of them. Thus, the absence of patents does not equate absence of innovation. Moreover, patenting is an expensive process, so firms in less developed countries tend to prefer other methods of protecting their innovations, which skews the data in favour of richer economies.

Patents are an interesting measure of innovation output, since they are the formal way of registering an innovation for intellectual property rights protection. However, there are some well-known problems with using patent data, the biggest being that there are many ways of protecting an innovation (trade secret, lead-time, complexity, etc.), and patenting is just one of them. Absence of patents thus does not necessarily imply absence of innovation in a country. Moreover, patenting is expensive, hence less developed countries tend to use this method of protection less frequently. Interesting conclusions can, however, still be drawn from analysing patent data.

In this indicator—total patents in force per USD 100 billion GDP[5]—we find that the shape of the LMICs' ladder changes quite significantly between 2010 and 2019, and becomes much steeper (**Figure 34**). The 2019 ladder is very steep, with the indicator being 13 times higher for UMICs, on average, than for LICs. This is, to a large extent, driven by China which more than tripled the number of patents in force from 2010 to 2019. The figure also shows how difficult it is for low- and lower middle-income countries to achieve the UMIC threshold for patents.

The figure includes some interesting examples of countries that reached their intra-group thresholds in the 2010–2019 period. This includes Afghanistan (LICs), Morocco (LMICs), and Malaysia (UMICs), among others.

Figure 34. Total patents in force per US$ 100 bn. GDP by income group, 2010–2019



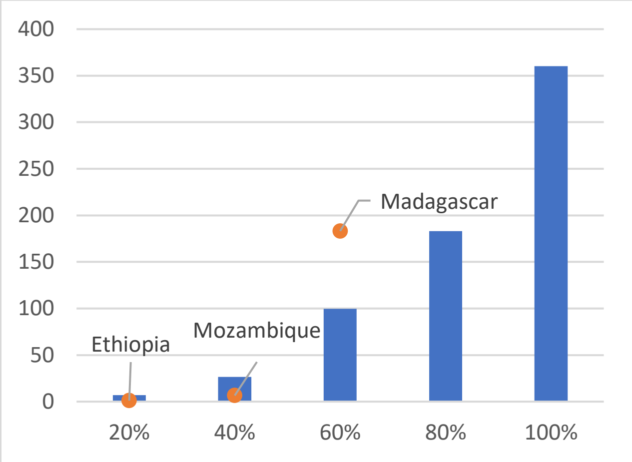
Steepness: 4.4

Steepness: 13.3

Note: Numbers in graph refer to height of bars.

[5] Due to the nature of this indicator, two countries with very small GDPs ended up having abnormally large values (Samoa and Marshall Islands). These were excluded from the graphs to avoid distortions. The Islamic Republic of Iran was also excluded from the analysis due to data inconsistencies.

Figure 35. Total patents in force per US$ 100 bn. GDP, low-income countries – Intra-group ladder (quintiles)



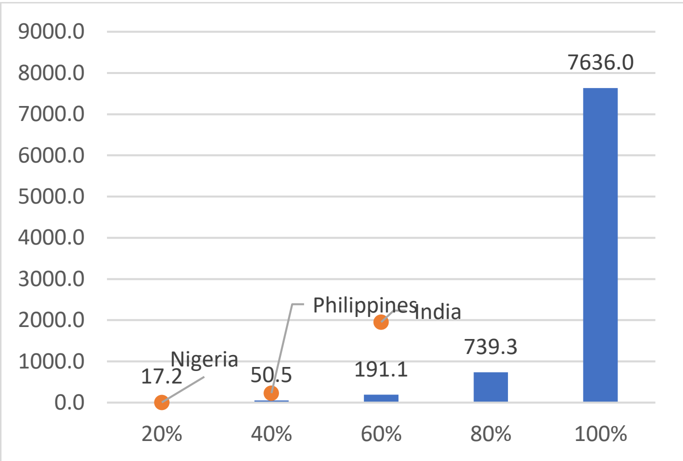
An interesting fact is that the intra-group ladders' steepness increases dramatically as the country's income level rises. Thus, while the steepness for the LIC group is 51.6, it is 445.0 for LMICs and 372.6 for UMICs (**Figure 35**, **Figure 36**, and

Figure 37, respectively).

Steepness: 51.6

Note: Numbers in graph refer to height of bars.

Figure 36. Total patents in force per US$ 100 bn. GDP, lower middle-income countries – Intra-group ladder (quintiles)

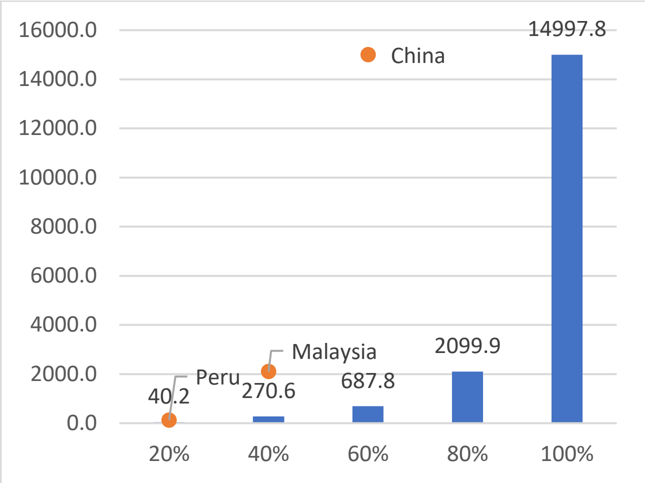


This means that some countries heavily skew the distribution, such as India, Ukraine and Mongolia in the LMIC group, and China, the Russian Federation and South Africa in the UMIC group (**Figure 36**).

Steepness: 445.0

Note: Numbers in graph refer to height of bars.

Figure 37. Total patents in force per US$ 100 bn. GDP, upper middle-income – Intra-group ladder (quintiles)



Analytically, this means that patents are an innovation output that is very difficult to achieve, with only a few low- and middle-income countries achieving the thresholds. It also means that patents might not be a prerequisite for basic levels of digitalization, its relevance applicable to more advanced digitalization, which requires a high indigenous capacity of developing and incrementally improving digital technologies.

Steepness: 372.6

Note: Numbers in graph refer to height of bars.

Indicator 14: Innovation output (royalties)

This indicator measures a country's innovation output based on its intellectual property rights (IPR) receipts. As a country becomes more technologically advanced, it starts licensing and exporting its technologies to other countries that pay royalties for them. This indicator measures how technologically advanced a country is, which is a useful proxy of how capable the country is in terms of absorbing and developing digital technologies. This indicator is measured by the value of IPR receipts per US$ 1,000 of GDP per capita.

Strategic questions:

- How many royalties were received for the use of domestically produced intellectual property?

Calculation: Innovation output (in terms of royalties) is calculated as:

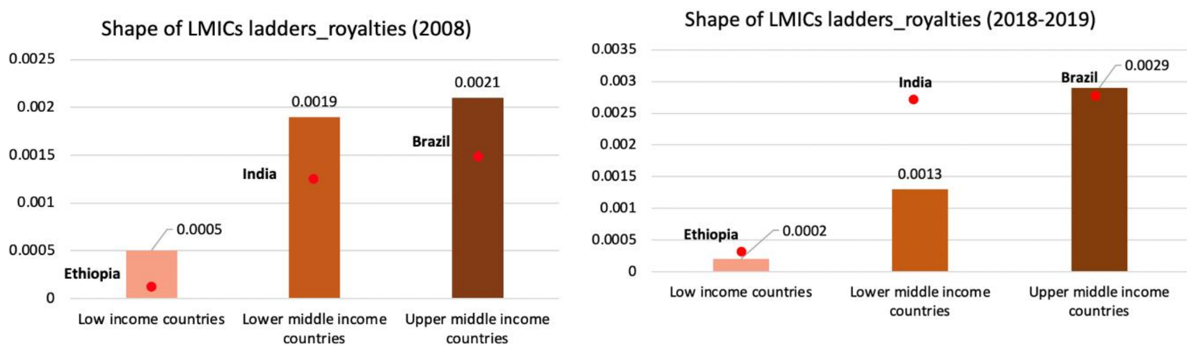
Innovation output (royalties) = $\frac{Intellectual\ property\ rights\ receipts}{GDP}$

Variables required	Data source	Notes
Intellectual property rights receipts Gross domestic product	International Monetary Fund, Balance of Payments Statistics Yearbook	Data are available for 72 LMICs for the 1976–2019 period

Please note: Using intellectual property rights receipts has the caveat that it only applies to technologies that are formally protected by intellectual property rights, such as patents. Thus, the same issues that play a role in the previous indicator, which uses patents, also apply here.

IPR payments (i.e. royalties) are charges for using the technology embodied in capital goods. Although it is impossible to determine which type of technology, i.e. whether it is advanced or old, this measure is a useful proxy of the use of foreign technologies. **Figure 38** shows the average of the three country groupings in 2008 and 2018/2019.[6] The steepness strongly increased over time; in fact, the LMICs bar is much closer to the UMICs' in 2008, indicating that over time, LMICs began lagging relative to UMIC. Among the selected countries, Ethiopia and India's positions improved from below their groups' average to higher levels, and outperforming countries in the same group. Brazil experienced a similar but less intense trajectory, and in 2018–2019, it was still slightly below its group average. However, it is interesting to note that while UMICs' average increased over time, the averages of LICs and LMICs decreased, possibly indicating a slowdown of less industrialized countries in terms of royalties.

Figure 38. Royalties payments by income group, 2008–2019



Steepness: 4.2

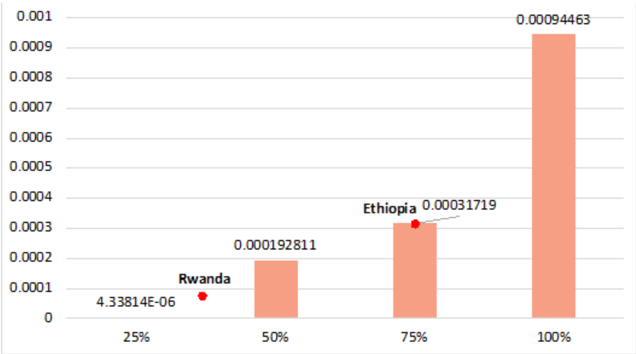
Steepness: 14.5

Note: Numbers in graph refer to height of bars.

The next section examines performance at the intra-group level. This indicates a country's position and how its progression might look like. The import of foreign technologies is an essential part of industrialization and development; as such, an improvement in position across the different bars of the ladders presented above is an essential step towards digitalization whose old and new forms are often embedded in foreign machinery. Different from other indicators, the steepness within each group increases with higher income levels.

[6] We used the latest available data between 2018 and 2019.

Figure 39. Royalties payments by low-income countries – Intra-group ladder (quartiles)

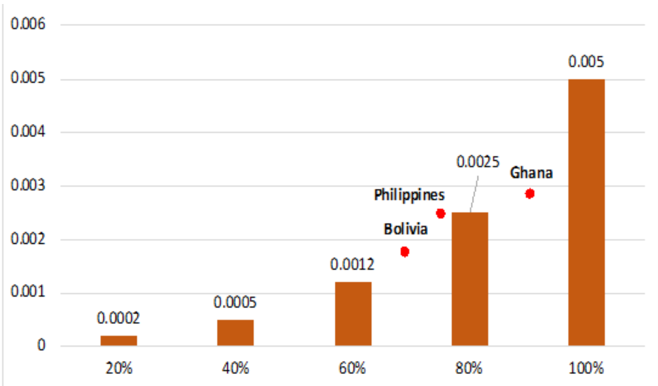


The distribution in quartiles reveals major differences (**Figure 39**). Nonetheless, countries that have started to industrialize, such as Ethiopia with its textile industry, are in a better position, as they need different types of (foreign) capital goods to manufacture their products.

Steepness: 217.74

Note: Numbers in graph refer to height of bars.

Figure 40. Royalties' payments by lower middle-income countries – Intra-group ladder (quintiles)



In LMICs (**Figure 40**), the steepness decreases to almost one-tenth. Countries such as The Philippines, Ghana and Bolivia are approaching the last quartiles. Again, this is strictly related with industrialization processes, and in particular with the dominant sectors in each country, as some sectors are more capital intensive and have to pay more royalties than others (e.g. Bolivia is a mining country).

Steepness: 25

Note: Numbers in graph refer to height of bars.

Figure 41. Royalties payments by upper middle-income countries – Intra-group ladder (quintiles)

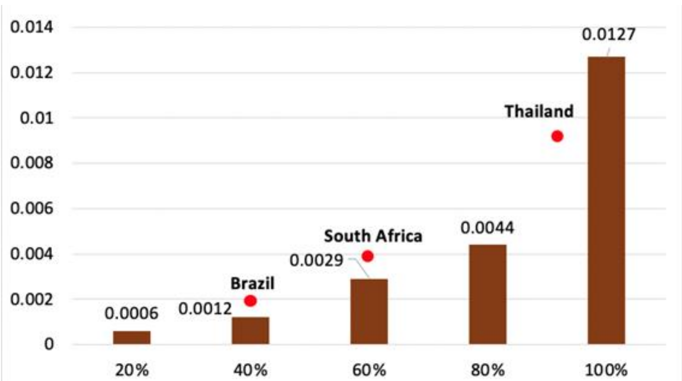


Figure 41 shows that the steepness decreases again for countries that are at a higher stage of development. One important aspect to note is sectoral composition: for example, South Africa imports a large amount of high-level technologies for both its mining and its automotive sector. One final note on China is that it is a major outlier, with the highest amount of royalties payments followed by Thailand.

Steepness: 21.16

Note: Numbers in graph refer to height of bars.

3.7 Digital capabilities

The fourth layer captures the exposure to and deployment of both technologies with digital potential as well as ADP technologies imports. This layer captures technological adaptation and learning from external digital technologies sources. To calculate the following indicators, the analyst must use a specific **digital technology classification**, which is discussed in the Annex.

Indicator 15: Imports of production technologies with digital potential

This indicator measures the country's capability to engage with production technologies that have digital potential. Acknowledging that digitalization is an incremental process that unfolds by mastering previous production technologies implies that assessing the amount of imports and the level of absorption of such technologies is critical.

Strategic questions:

- How many products with digital potential are imported by the country?

Calculation: Absorption and exposure to production technologies with digital potential is calculated as:

Imports of production technologies with digital potential = $\frac{Imports\ of\ PTDP}{GDP}$

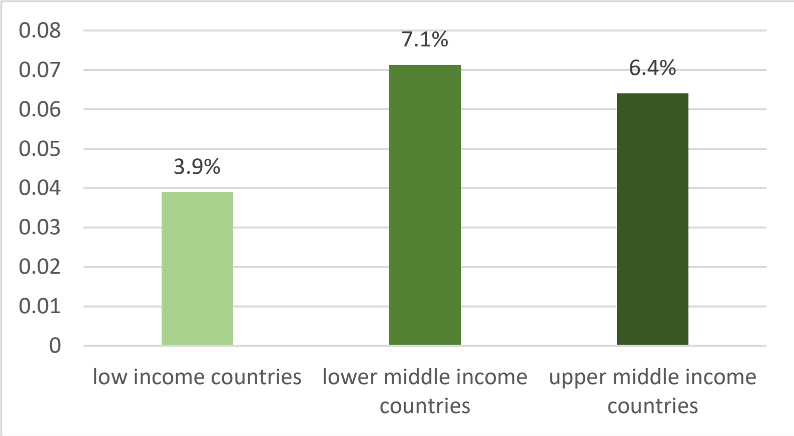
Variables required	Data source	Notes
Imports of products with digital potential Gross domestic product	HS data from UNCOMTRADE World Development Indicators	The classification used to identify PTDP is discussed in the Annex. The use of GDP serves to normalize for country size, which seems to be the most reliable scale

Please note: Details on where and how to download detailed trade data are discussed in the trade-related EQuIP Tools 2, 3 and 4.

The first indicator of digital capabilities is the amount of production technologies imports with digital potential/GDP. As illustrated in **Figure 42**, the share of production technologies in LMICs' GDP is limited. However, machinery imports can be utilized in all productive sectors of the economy. They range from agricultural machinery, to drills and ducts for the mining industry, manufacturing machinery, and hospital and medical equipment. Therefore, these technologies have an impact on the entire economy, and are not limited to their own sectors.

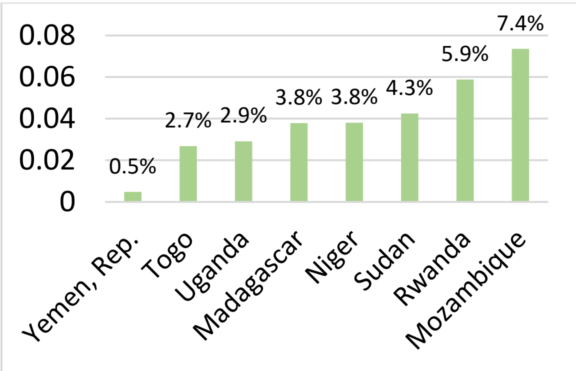
Another interesting fact is that the value for UMICs is slightly lower than that of LMICs. This is because some lower middle-income countries such as Viet Nam have very high values, which pulls the distribution upwards. This may also point to the fact that in some cases, as the economy grows and becomes more industrially complex, the country starts to partially produce its own machinery—such as in the case of Brazil—and thus reduces its imports of such products.

Figure 42. Imports of production technologies with digital potential as a share of GDP by income group, 2018



Note: Numbers in graph refer to height of bars.

Figure 43. Import of production technologies per GDP, 2018 – LICs



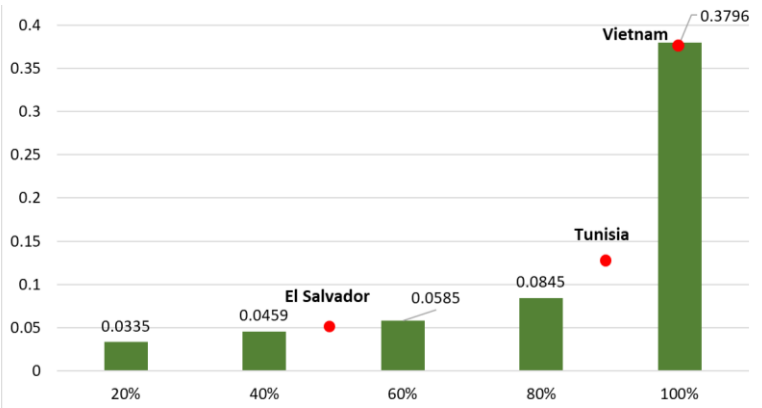
Looking at the intra-group ladders in

Figure 43, we find that the LIC ladder is more linear than the LMIC and UMIC ladders.

In the LIC ladder, the values range from 0.5 per cent (Yemen) to 7.4 per cent (Mozambique). These higher values in the LIC group are comparable with the high quintiles in both the LMIC and UMIC ladders.

Note: Numbers in graph refer to height of bars.

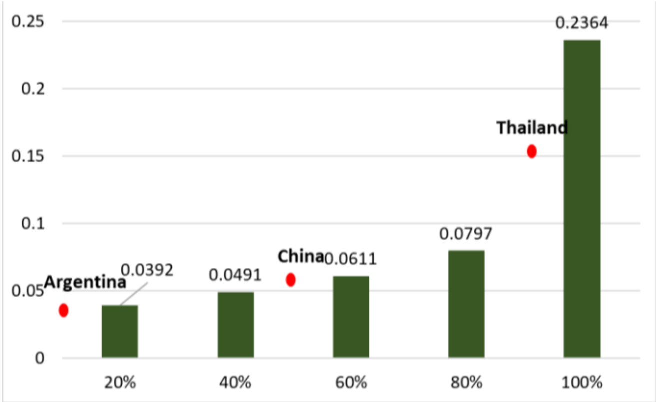
Figure 44. Imports of production technologies per GDP, 2018 – LMICs



However, there are some countries in the LMIC ladder (**Figure 44**) that are in stark contrast with the other countries, such as Viet Nam (38 per cent) and Tunisia (13 per cent). In contrast, there are also countries with very low values, such as Tanzania (2 per cent) and Myanmar (4 per cent).

Note: Numbers in graph refer to height of bars.

Figure 45. Imports of production technologies per GDP, 2018 – UMICs



Note: Numbers in graph refer to height of bars.

The UMIC ladder (**Figure 45**) also includes countries at the top that pull the distribution upwards, such as Malaysia (23 per cent) and Thailand (14 per cent). At the other end, we find Brazil (2 per cent) and Argentina (3 per cent) – although this may be because these countries partially produce their own machinery.

Indicator 16: Imports of digital production technologies, parts and instruments

This indicator measures imports of ADP (advanced digital production) technologies as an aggregate value of production technology, parts or components and technology instrumentations. As a country's digital capabilities are upgraded and it starts to engage with fully fledged digital production technologies, it needs to import such technologies and adapt them for deployment in its local production system. The learning process countries must embark on to be able to engage in digital manufacturing entails a period of importing more sophisticated technologies that are likely to be produced in advanced and fast industrializing economies.

This indicator is built as a ratio between digital production technologies (i.e. the digital classification which consists of 156 product classes discussed in the Annex) and GDP.

Strategic questions:

- How many products characterized as advanced digital production technology are imported by the country?

Calculation: Imports of digital production technologies, parts and instruments are calculated as:

Imports of digital production technologies, parts and instruments = $\frac{Imports\ of\ digital\ products}{GDP}$

Variables required	**Data source**	**Notes**
Imports of digital products	HS data from UNCOMTRADE	The classification used to identify digital products is discussed in the Annex
Gross domestic product	World Bank World Development Indicators	

Please note: Caution should be taken when using this indicator for countries with a very low GDP, as the low denominator may distort the indicator and make it see that the country is performing well, despite low engagement with digital products.

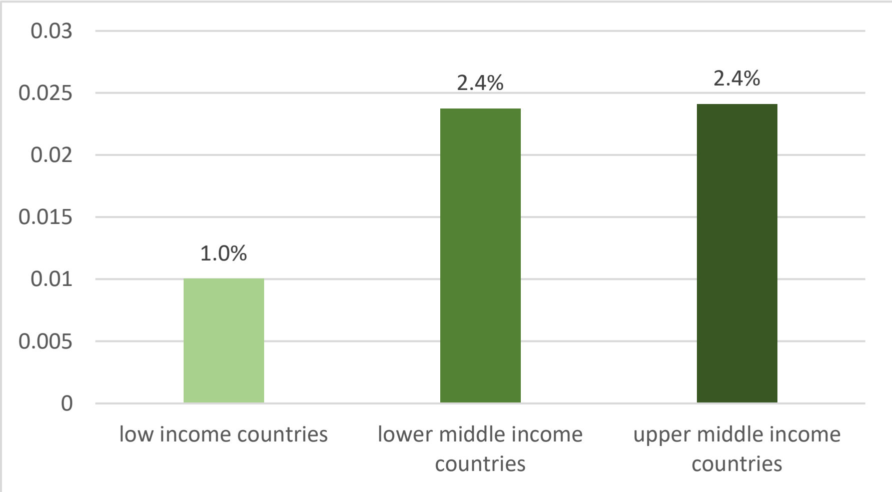
Details on where and how to download detailed trade data are discussed in the trade-related EQuIP Tools 2, 3 and 4.

LMICs ladder: understanding a country's position before climbing up

The second indicator is the import of digital production technologies (DPTs), digital parts and digital instrumentation technologies as a share of GDP. This covers the 156 digital products selected based on our methodology. As shown in **Figure 46**, such technologies represent a very small fraction of the countries' GDP, but these technologies nonetheless have wide-ranging applications and their importance for industrial competitiveness is increasing as digitalization processes continue to spread.

The big step in this ladder seems to be from the LIC to the LMIC level, as the indicator's value from the LMIC to the UMIC level is the same. The similarity between these two is attributable to some LMIC countries, such as Viet Nam, that pull up the distribution.

Figure 46. Imports of DPTs, parts and instruments as share of GDP by income group, 2018



Note: Numbers in graph refer to height of bars.

Indicator 17: Exports of digital production technologies, parts and instruments

Differently from the import indicators above, this indicator measures the country's competitiveness in digital technologies by measuring its exports of these products. It is assumed that if the country exports these products, it possesses digital-related capabilities. There are, however, some caveats to consider, as the exports may be largely (or fully) attributed to multinational corporations, with limited knowledge spillovers to the local economy. Alternatively, they can be carried out by local firms engaged in low value-added segments of a GVC (see EQuIP Tool 4). Despite its limitations, this indicator still provides interesting insights into a country's capabilities and potential for digitalization.

Strategic questions:

- To what extent are digital products being exported?

Calculation: Exports of digital technologies is calculated as:

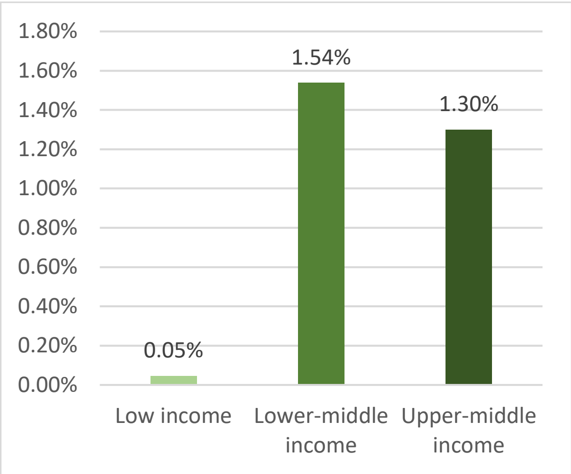
Exports of digital technologies = $\frac{Exports\ of\ digital\ products}{GDP}$

Variables required	Data source	Notes
Exports of digital products	HS data from UNCOMTRADE	The classification used to identify PTDP is discussed in the Annex
Gross domestic product	World Bank World Development Indicators	

LMICs ladder: understanding a country's position before climbing up

The third indicator of a country's digital capabilities is the export of DPTs, digital parts and digital instrumentation technologies as a share of GDP. These were calculated based on the 156 products using the classification discussed in Annex A1.

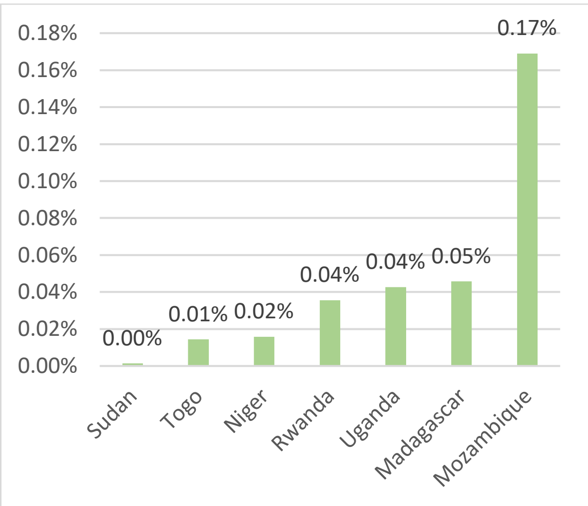
Figure 47. Exports of digital products by income group



Note: Numbers in graph refer to height of bars.

As shown in **Figure 47**, the export of these products only accounts for a small percentage of each countries' GDP, especially in LICs (0.05 per cent, on average). Interestingly, the average for LMICs is again higher than that for UMICs. This is attributable to some LMICs with very high values, e.g. Viet Nam, which pulls the LMIC distribution upwards. Moreover, as countries develop, their economies may diversify, resulting in proportionally larger GDP compared to their exports, especially of specific digital products.

Figure 48. Exports of digital products, low-income countries – intra-group ladder

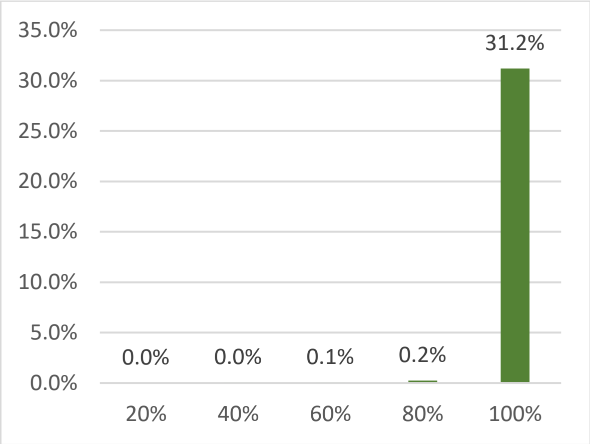


Note: Numbers in graph refer to height of bars.

In the intra-group ladders, we we again see a larger skeweness for LMICs (**Figure 49**) and UMICs (**Figure 50**) compared to LICs (**Figure** 48).

However, the distribution in the case of LICs is also skewed, with Mozambique's value being consideably higher than that of the other LICs, albeit at a very low level (0.17%) (**Figure 48**).

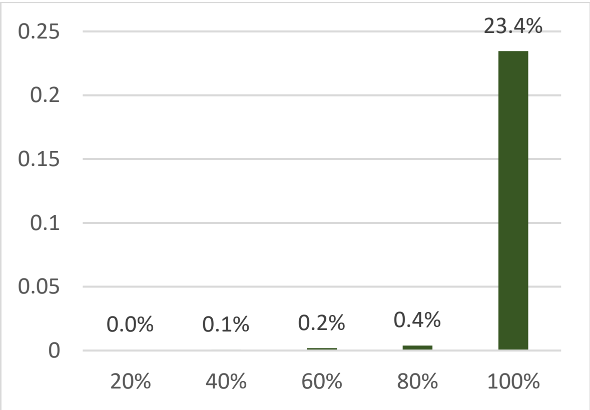
Figure 49. Exports of digital products, lower middle- income countries – intra-group ladder



Note: Numbers in graph refer to height of bars.

LMICs has one extreme outlier—Viet Nam (31 per cent)—followed by Tunisia at 2.6 per cent (Figure 49). Digital product exports account for almost **one-third** of Viet Nam's GDP.

Figure 50. Exports of digital products, upper middle-income countries – intra-group ladder

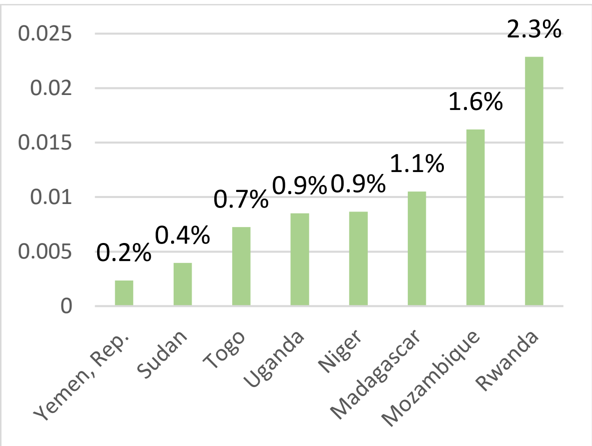


Note: Numbers in graph refer to height of bars.

UMICs have one extreme outlier – Malaysia (23 per cent) (**Figure 50**), followed by Thailand (8 per cent) and China (5 per cent). Considering the size of China's GDP, it is surprising that of the country's digital product exports only account for 5 per cent of its GDP.

For reference, the absolute value of China's exports of such products is US$ 661 billion, Malaysia's is US$ 84 billion, and Viet Nam's is US$ 76 billion.

Figure 51. Imports of DPTs, parts and instruments by GDP, 2018 – Low-income countries

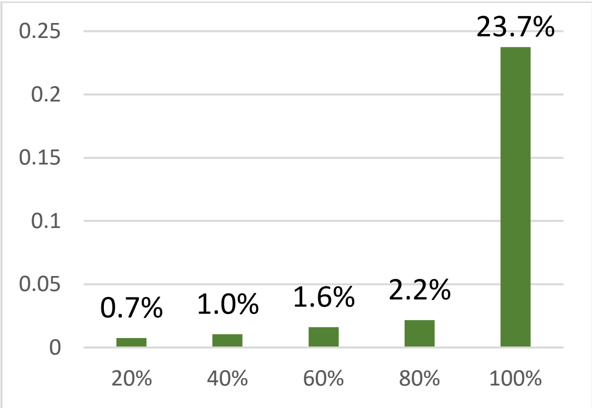


Note: Numbers in graph refer to height of bars.

Looking at the intra-group ladders, we once again find that the LMICs (**Figure 52**) and the UMICs (**Figure 53**) ladders are much more skewed than that of the LICs (**Figure 51**).

LIC countries with higher values (Rwanda, Mozambique) are again aligned with the higher values of LMIC and UMIC countries (**Figure 51**). The significant differences seem to be attributable to a few countries.

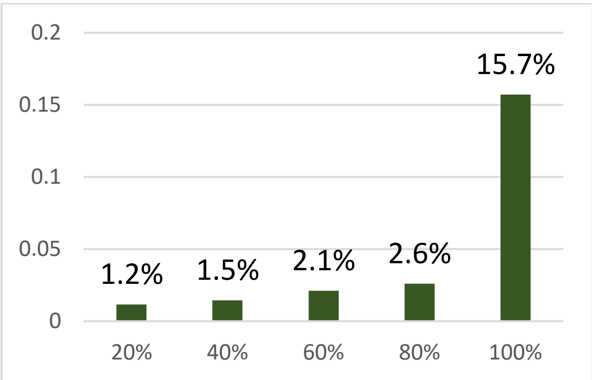
Figure 52. Imports of DPTs, parts and instruments by GDP, 2018 – Lower middle-income countries



Note: Numbers in graph refer to height of bars.

In LMICs, the outlier is Viet Nam (23 per cent), followed by Tunisia (4 per cent) (**Figure 52**).

Figure 53. Imports of DPTs, parts and instruments, 2018 – Upper middle-income countries



Note: Numbers in graph refer to height of bars.

In UMICs, the outliers are Malaysia (16 per cent) and Thailand (7 per cent) (**Figure 53**).

Indicator 18: Imports of computer and information services

One important consideration is the use and provision of digital services. This is particularly relevant for digitalization because many digital technologies need digital services to operate, or will only provide benefits if they are used in conjunction[7] with digital services (such as software engineering services to interconnect objects, data analytics services such as business intelligence, data processing and storage services such as cloud computing, etc.). Imports of computer and information services is directly related to digitalization as it includes hardware and software-related services, data processing services and database services. These services are essential for the functioning of digitalized production, so a country with a high level of imports of such services demonstrates active engagement with digital technologies.

[7] See EQuIP Tool 4 for a discussion on services used as inputs in value chains.

Strategic questions:

- How many computer and information services were imported?

Calculation: Imports of computer and information services are calculated as:

Imports of computer and information services = $\frac{Imports\ of\ computer\ and\ information\ services}{GDP}$

Variables required	Data source	Notes
Imports of computer and information services	UNCOMTRADE, EBOPS 2002 classification	Details discussed in the Annex
Gross domestic product	World Bank World Development Indicators	

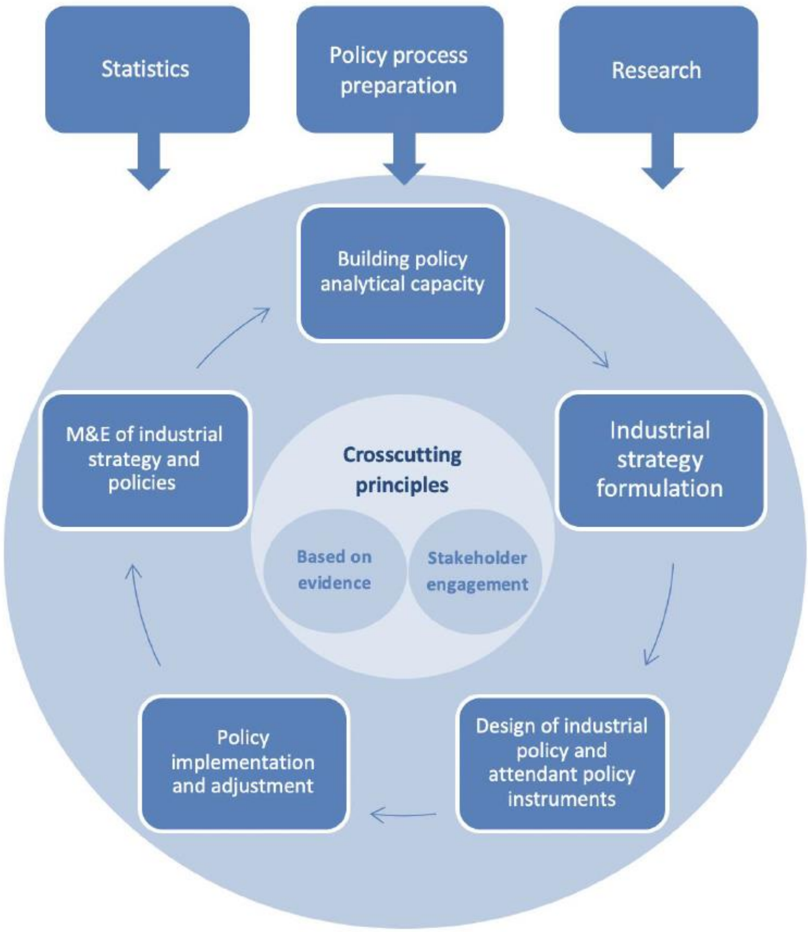
4 Policy options

4.1 How to use EQuIP for industrial strategy and policy design

The following text provides a brief overview of how to use the EQuIP tool in strategy and policy design. A full discussion is available in *EQuIP Tool 0: Evidence for industrial policymaking*.

Industrial policymaking can be described as a cyclical or iterative process (**Figure 54**).

Figure 54. Industrial policy cycle



In the diagnostic phase, which requires analytical capacities, evidence (e.g. based on quantitative and qualitative data) is collected, systematically processed and used to identify policy challenges. Industrial strategies and related industrial policies are then defined to address these challenges. Industrial policy goals determine the choice of intervention areas and the formulation of suitable policy instruments. The implementation of these instruments is monitored and evaluated, with the results feeding back into diagnostics and evidence collection on progress made towards the intended industrial development targets, completing the policymaking cycle. The cycle's iterative nature implies that industrial strategies and policies align with the progress achieved in the country's industrial development journey. In this dynamic process of accumulation and adjustment of industrial capabilities, emerging industrial development challenges and opportunities are continuously addressed.

EQuIP diagnostic tools are designed to support the policymaking process. By implementing training programmes, they aim to increase policymakers' analytical capacities and address the following three components of the policy cycle:

- Building policy analytical capacity – diagnostics
- Industrial strategy and policy formulation
- Monitoring and evaluation.

Building policy analytical capacity – diagnostics

Conducting a comprehensive, multidimensional assessment of the present situation and performance of the industrial sector is the first step in the policymaking cycle. The EQuIP diagnostic tools provide a solid foundation for such an assessment, which covers a range of economic, social and environmental aspects. Each tool uses data-driven methodologies that serve as a reliable starting point for identifying areas that require further investigation. Additional in-depth examinations can take the form of additional quantitative research, such as using nationally available data, or qualitative research, such as reviewing existing reports, conducting interviews, or consulting national stakeholders and experts. Such comprehensive assessments of the country's industrial sector on different economic, social and environmental aspects establish a minimum evidence base from which (evidence-based) strategies and policies can be formulated.

Industrial strategy and policy formulation

The process of strategy and policy design should be goal-oriented, evidence-based and involves decision-making at five stages.

The first step is to determine which **national development goals** industrial strategy and policy can best contribute to.

The second step in the process is to design the **industrial development strategy**, which provides a general long-term view. This strategy outlines how inclusive and sustainable industrial development (ISID) contributes to national development goals.

Based on the objectives embedded in the industrial development strategy, the associated **industrial policy** elaborates the roadmap for achieving the strategic goals in greater detail. Industrial policy often narrows the scope of interventions, either by establishing general framework conditions for all economic activities (horizontal policy), or by providing targeted support to selected industries (vertical). The industry-related **objectives** outlined in the policy reflect the policy's explicit goals for achieving ISID. These goals need to be detailed, measurable, achievable, relevant and time-bound (SMART), taking the country's capabilities and limitations into account.

To achieve these objectives, concrete changes in the behaviour of economic actors or the overall business environment are necessary. The **intervention areas** are derived from the objectives and specify the required changes.

The evidence derived from applying the EQuIP diagnostic tools can contribute to all of the steps described above, as they help identify the strengths and weaknesses of a country's industrial sector and its subsectors, and provide insights into the country's past developments and offer comparisons with other countries.

Once the intervention areas have been defined, policymakers must select **policy instruments**, i.e. develop specific government interventions that will drive the necessary changes. Policy instruments are tools used to shape public- and private sector activities to achieve the specific goals set by the policy. Typically, several instruments are needed to achieve the intended outcome, hence necessitating the creation of a **mix of policy instruments** or a policy portfolio.

Designing a policy instrument entails determining the objective it pursues, the type of intervention to implement, the expected outputs, the strategy to achieve the predefined results, the beneficiaries or target groups, access regulations (competitive or accessible to all beneficiaries), the source and amount of funding and the time frame.

Monitoring and evaluation

The EQuIP diagnostic tools provide indicators and a logical sequence of decisions for designing strategies and policies for industrial development and serve as a starting point for establishing a monitoring and evaluation (M&E) system. Such a system is essential for monitoring and evaluating not only policies, but also all types of interventions or instruments. Monitoring is a continuous process that provides regular feedback on progress towards achieving milestones and the intended results. It focuses primarily on tracking spending in relation to an intervention, and whether the activities are being implemented according to the roadmap. Evaluation, on the other hand, involves regular reviews of the intervention's results and its impact on the intended outcomes. The purpose of evaluation is to determine whether an intervention has the anticipated effects and whether it contributes to the continuous policy learning process that makes industrial policymaking inherently cyclical and iterative in nature (Figure 54).

The following subchapters address policy options that are specific to this tool.

4.2 Digital policy: From indicators to policy instruments

Digital production technologies (DPTs) are complex and are controlled by a limited number of advanced countries and their leading companies (IDR 2020, UNIDO). Developing countries heavily rely on the imports of these technologies from advanced economies, even when they can mobilize significant resources to access such technologies, developing countries are tied to their buyers both with respect to hardware and software components. Many of these technologies are not "plug and play", that is, the acquisition of hardware goes hand-in-hand with the need for expensive technology services and royalties for the use of the related software (Sturgeon, 2017; Piva and Vivarelli, 2017). International buyers and original equipment manufacturers (OEMs) control the source, type and use of DPTs by setting the parameters of supplier engagement. Those who cannot meet these parameters are excluded. The use of common protocols and software platforms for the deployment of DPTs carries the risk of a verticalization and concentration of power.

While the use of ADP technologies is accelerating in late industrializers such as China and India, these technologies remain concentrated in a few sectors and companies and supply chains within them. The full automation of "routinized tasks" is far from diffused as many observers seem to suggest. There are multiple reasons for this, including infrastructural preconditions and trade-offs associated with DPTs, both with respect to the hardware and software of these technologies and, even more critically, their production system integration. Having said that, 4IR islands have started connecting and cross-sectoral value chains using ADP technologies are gradually emerging, also due to governments' industrial policies, such as in the case of Thailand and Malaysia.

Companies in middle-income countries such as Brazil and South Africa, are facing more fundamental problems in terms of access to ADP technologies, their integration into existing production systems and their retrofitting, as well as sufficient availability of basic production- and enabling infrastructural capabilities. Constraints to job creation are largely the result of structural and political economy problems, including premature de-industrialization, lack of productive organizations in key segments of GVCs and of basic productive capabilities, more than the actual diffusion of ADP technologies. In countries such as Thailand and Viet Nam, where the configuration of the political economy configuration—developmental state coalition—has led to high levels of investments and increasing numbers of export-led competitive companies, the governments are pushing for the diffusion of ADP technologies beyond 4IR islands.

The lack of competitive productive organizations in least developed countries, especially in Africa, limits the deployment of ADP technologies even more. While some basic information and communication technologies (ICTs) are being used, for example in the management of money transactions (e.g. online finance platforms) or in the sharing of some basic data (e.g. price data in agriculture), these are actually applications of the third industrial revolution rather than truly ADP technologies. A limited number of companies involved in production activities are experimenting with the use of DPTs. For example, some experimental applications are found in some high value agricultural products, extractive processes and trade logistics. Unfortunately, given the limited amount of manufacturing industries and competitive companies in these countries, they are still unable to capture the potential "digital dividend" of ADP technologies.

The different levels of countries' engagement with ADP technologies is driven by their existing production structure and the extent to which they are equipped with the necessary foundational capabilities. Digital industrial policy plays an important role in building these capabilities on the stairway to digitalization. We review four country cases to highlight potential policy instruments governments can use to address capability gaps using the digital readiness diagnostic tool.

4.3 Digital Readiness Heatmap Dashboard

Foundational capabilities for digitalization are not substitutable but rather highly complementary. Outperforming in certain indicators, for example basic skills, will not compensate lower than average performances in other indicators, for example, digital connectivity. Because digital readiness is multidimensional, each indicator must be analysed separately. However, governments that conduct analyses of digital readiness for each specific indicator will *also* need to assess the economy's overall digital readiness. Governments can supplement indicator-focused analyses with a heatmap dashboard analysis.

The *Digital Readiness Heatmap Dashboard* is a benchmarking tool constructed around the indicators introduced later in this section. As shown in Error! Reference source not found. and illustrated in **Table 3** for a selected group of countries, the dashboard allows a visualization at the same time:

- the performance of one country across all indicators
- the performance of one country across all indicators, alongside the performance of other countries from different income groups LICs, LMICs and UMICs
- the indicators in which the country is under- or outperforming relative to the average performance of its close comparators (inter-group comparison)
- the indicators in which the country is under- or outperforming against the average performance of its higher income comparators (intra-group comparison)
- the steepness of the ladder for each specific indicator, hence how much effort will be necessary to improve the country's performance.

The dashboard adopts a light system—red, yellow and green—to highlight those indicators countries need to focus their efforts on if they want to climb up the digitalization ladder.

Box 10. Digital Readiness Heatmap Dashboard – Light system

A red light means that the country's performance in the specific indicator is below the average performance of lower middle-income countries;

A yellow light signifies that the country's performance in the specific indicator is above the average performance of lower middle-income countries, but below the average performance of upper middle-income countries;

A green light indicates that the country's performance in the specific indicator lies above the average performance of upper middle-income countries.

Table 3. Heatmap Dashboard for selected low- and middle-income countries (LMICs)

Indicator	Measure	Year	LMICs average	UMICs average	Steepness	Argentina	Brazil	Peru	Colombia	Bolivia	South Africa	Ghana	Nigeria	Ethiopia	Kenya	Mozambique	Rwanda	China	Russian Federation	India	Indonesia	Thailand	Viet Nam	Malaysia	Phillipines
Energy availability	Electricity consumption per capita	2019	901.5	2749.5	13.2	2962.9	2915.7	1706.6	1490.7	845.9	4008.9	397.2	177.5	130.1	217.3	505.3	62.0	5110.0	7256.1	1008.6	1038.8	2636.0	2689.6	5096.5	928.4
Energy reliability	Percentage of firms experiencing electrical outages	2017	65.4	55.6	0.8	0.8	45.8	52.2	53.9	35.1	92.0	89.1	77.6	80.0	82.8	52.8	39.0	33.7	15.1	55.4	22.5	8.6	26.3	18.9	39.9
Access to digital connectivity	Fixed broadband subscriptions per 100 people	2019;2018	4.1	13.7	22.1	19.6	15.6	7.9	13.8	6.5	2.1	0.2	0.0	-	0.9	0.2	0.1	31.3	22.5	1.4	3.8	14.5	15.3	9.3	5.5
Quality of connectivity	Mean download speed (Mbps)	2020	6.0	12.4	3.7	6.2	17.9	8.0	8.8	5.1	14.0	5.5	3.3	1.1	8.2	3.5	3.8	2.1	25.0	13.5	7.2	30.6	13.4	46.8	8.8
Productive investments	Share of GFCF % GDP	2017-2018	25.7	21.8	1.0	14.7	15.1	20.9	21.2	20.2	18.2	23.2	19.0	34.7	17.3	26.9	23.0	42.8	20.7	29.2	32.3	22.8	23.9	24.2	27.3
Productive skills	Mean years of schooling	2017-2018	7.5	9.8	3.4	11.1	8.0	9.8	8.5	-	10.1	-	-	-	-	3.1	4.3	-	-	-	8.2	8.4	-	-	8.4
Operational efficiency	ISO 9001 certificates	2019	0.027	0.238	3.3	0.003	0.091	0.002	0.000	0.007	0.004	0.001	0.018	0.027	0.013	0.030	0.044	0.062	0.059	0.000	0.036	0.002	0.003	0.033	0.242
Technology absorption	Intellectual Property Right payments (royalties) per GDP	2018-2019	0.001	0.003	14.5	0.004	0.003	0.002	0.004	0.002	0.005	0.003	0.001	0.000	0.001	0.000	0.000	0.002	0.004	0.003	0.002	0.010	-	0.006	0.002
Specialised skills	Percentage of graduates from STEM programmes in tertiary education	2019; 2018	24.2	20.6	1.3	16.0	18.4	-	24.6	-	18.3	16.4	-	-	-	9.6	13.0	-	31.1	32.2	19.4	-	-	39.2	-
Advanced skills	Gross enrolment ratio in tertiary education	2019; 2018	23.3	50.6	4.0	91.6	53.3	-	55.0	-	23.8	17.2	-	-	-	7.3	6.2	53.8	84.6	28.6	36.3	-	28.6	43.1	-
Research effort	Gross Expenditure in R&D as a % of GDP	2018; 2017	0.3	0.6	2.2	0.5	1.2	0.1	0.2	-	0.8	-	-	0.3	-	-	-	2.1	1.0	0.7	0.2	1.0	0.5	1.0	-
Research output	Scientific and technical journal articles per million people	2018	44.7	166.6	24.1	198.0	287.1	51.0	144.9	9.1	225.1	42.9	28.6	18.3	24.3	4.7	13.8	379.3	564.6	100.4	100.7	180.2	44.9	750.5	21.0
Innovation output (patents)	Total patents in force per 100 bi USD GDP	2019	648.7	3149.5	30.9	412.2	687.8	125.2	532.1	46.5	4281.1	8.9	5.6	1.0	92.1	6.5	-	14997.8	10419.3	1952.8	29.8	510.8	512.0	2099.9	231.7
Innovation output (royalties)	Intellectual Property Right receipts (royalties) as a % of GDP	2020;2019	182.1	459.2	3.6	559.1	439.0	132.6	445.9	175.3	324.6	1111.6	-	-	660.2	-	17.5	581.0	784.6	477.9	79.0	449.1	-	687.7	42.2
Absorption and exposure to production technologies with digital potential	Imports of production technologies as a share of GDP	2018	0.0713	0.064	1.6	0.03	0.02	0.04	0.03	0.06	0.05	0.03	-	-	-	-	-	0.06	0.04	0.03	0.05	0.14	0.38	0.24	-
Deployment and adaptation of digital production technologies	Imports of digital products as a share of GDP	2018	0.0237	0.0241	2.4	0.01	0.01	0.01	0.01	0.01	0.02	0.01	-	-	-	0.02	0.02	0.04	0.02	0.02	0.01	0.07	0.24	0.16	-
Industrial competitiveness in digital technologies	Exports of digital products as a share of GDP	2018	1.54%	1.30%	28.0	0.03%	0.08%	0.02%	0.04%	0.03%	0.33%	0.01%	-	-	-	0.17%	0.04%	4.76%	0.18%	0.21%	0.38%	7.63%	31.20%	23.44%	-

Source: Authors

4.4 Digital policy case study: Thailand

Thailand's rapid socio-economic development is particularly interesting for countries that aim to achieve similar results. Despite the fact that each country has specific characteristics and the 'one size does not fit all' argument still holds, Thailand's experience confirms the importance of pursuing industrial development as a cornerstone for socio-economic upgrading (Natsuda and Thoburn, 2013 for a focus on industrialization stemming from the automotive sector). Thailand is one of the fastest-growing emerging economies, successfully attracting foreign direct investment and developing into a central hub in the region for critical sectors such as plastic and automotive industries.

Table 4. Thailand Dashboard

Indicator	Measure	Year	LMICs average	UMICs average	Steepness	Thailand
Energy availability	Electricity consumption per capita	2019	901.5	2749.5	13.2	2636.0
Energy reliability	Percentage of firms experiencing electrical outages	2017	65.4	55.6	0.8	8.6
Access to digital connectivity	Fixed broadband subscriptions per 100 people	2019;2018	4.1	13.7	22.1	14.5
Quality of connectivity	Mean download speed (Mbps)	2020	6.0	12.4	3.7	30.6
Productive investments	Share of GFCF % GDP	2017-2018	25.7	21.8	1.0	22.8
Productive skills	Mean years of schooling	2017-2018	7.5	9.8	3.4	8.4
Operational efficiency	ISO 9001 certificates	2019	0.027	0.238	3.3	0.002
Technology absorption	Intellectual Property Right payments (royalties) per GDP	2018-2019	0.001	0.003	14.5	0.010
Specialised skills	Percentage of graduates from STEM programmes in tertiary education	2019; 2018	24.2	20.6	1.3	-
Advanced skills	Gross enrolment ratio in tertiary education	2019; 2018	23.3	50.6	4.0	-
Research effort	Gross Expenditure in R&D as a % of GDP	2018; 2017	0.3	0.6	2.2	1.0
Research output	Scientific and technical journal articles per million people	2018	44.7	166.6	24.1	180.2
Innovation output (patents)	Total patents in force per 100 bi USD GDP	2019	648.7	3149.5	30.9	510.8
Innovation output (royalties)	Intellectual Property Right receipts (royalties) as a % of GDP	2020;2019	182.1	459.2	3.6	449.1
Absorption and exposure to production technologies with digital potential	Imports of production technologies as a share of GDP	2018	0.0713	0.064	1.6	0.14
Deployment and adaptation of digital production technologies	Imports of digital products as a share of GDP	2018	0.0237	0.0241	2.4	0.07
Industrial competitiveness in digital technologies	Exports of digital products as a share of GDP	2018	1.54%	1.30%	28.0	7.63%

Using the heatmap dashboard presented in **Table 4** as a starting point, this case study examines how Thailand was able to improve the '*quality of connectivity*' and the '*deployment and adaptation of digital production technologies'* indicators with a series of consistent policies. The country-level dashboard shows that Thailand's performance in nearly all indicators considered is exceptional, apart from ISO 9001 certificates and total patents produced. Otherwise, Thailand generally ranks above its country group average, and performs particularly well in infrastructure capabilities and digitalization capabilities. Investment in basic and intermediate capabilities drive a consistent trajectory towards digitalizing the productive structure (Deloitte, 2020). For example, in terms of the adoption of industrial robots, Thailand ranks among the top 5 emerging economies and first among the ten members of the ASEAN (Association of Southeast Asian Nations) countries (Andreoni and Anzolin, 2019). Thailand has invested heavily in and incentivized robotization and internet penetration. By contrast, the dashboard locates Thailand below its group average in terms of research efforts and output. The "green lights" that characterize Thailand's profile across the different indicators signal the country's readiness for digital transformation, a process that has been co-shaped by a series of policy interventions.

"Thailand 4.0" is a sector-specific policy that aims to attract new investments to transform the economy. The policy, which was presented in May 2016, was established to enhance the integration of national development agendas with other development plans such as the National Sustainable Development Goals (Wongwuttiwat and Lawanna, 2018). "Thailand 4.0" was intended as complementary to the wider 12th National Economic and Social Development Plan (2017–2021)[8], which is part of the 20-year National Strategy (2017–2036). Such strategies aim to pull the country out of the "middle-income trap" and transform Thailand into a "value-based" economy (Yoon 2016), by placing regional connectivity and manufacturing production at the centre of the strategy. Due to Thailand's particularly high score in infrastructure capabilities and digitalization capabilities, we explore two indicators from these layers and discuss some of the policies that contributed to the country's strong performance.

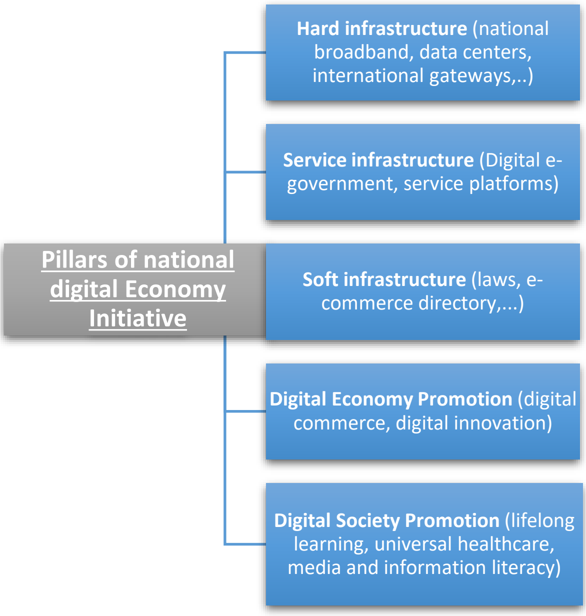
Enabling infrastructure for digitalization – quality of connectivity

The first set of indicators measures a country's effort to build up the preconditions, e.g. the necessary infrastructure to digitalize the productive structure. Thailand performs above its group's average in three out of four indicators, with an exceptional performance in one indicator, namely the quality of connectivity measured by the mean download speed. Good quality connectivity is crucial for setting up online wireless machines as well as the use of software programmes such as ERP, PLC and MES, which are critical steps in digitalizing manufacturing processes.

The digitalization process started at the beginning of this century, building on the two main pillars, the IT Policy Framework 2002–2010 and the ICT Policy Framework 2011–2020, aimed at developing the fundamental preconditions. At least 80 per cent of the population had access to the broadband network by 2015, and 95 per cent by 2020, while a standard quality of the service and reasonable service fees were pursued. In 2016–2017, 11,250 villages were connected to high-speed internet and 150,000 to WIFI access points and 2,500 telecentres were set up in schools, health facilities and community centres.

[8] In June 2016, the National Legislative Assembly of the Thai government approved the establishment of the new Digital Ministry. In the same year, the government replaced the Ministry of Information and Communication Technology (which was mainly focused on infrastructure) with the Ministry of Digital Economy and Society.

Figure 55. Pillars of Thai national digital economy initiative



The creation of the digital infrastructure fund facilitated the implementation of programmes such as MOENet and OBECNet, with the aim of establishing fibre connections to universities (1-2 Gbps), schools and public libraries (10-100 Mbps). Demand-side support from the government remained stable and consistent through investments in e-Government, e-Education, e-Healthcare and e-Agriculture (e.g. Sagarik et al., 2018; Wongsim et al., 2018). **Figure 55** presents the main pillar of the National Digital Economy Initiative.[9]

Digitalization capabilities – deployment and adaptation of digital production technologies

Our indicators use trade data to measure the level of digital absorption, deployment and competitiveness of production technologies with digital potential. Together with Viet Nam and Malaysia, Thailand tops the list of both imports and exports of such technologies. Focussing on Thailand, specific policies have been introduced in the past ten years to foster the development of production technologies. The first target at the industrial level are the five key industries that are part of Thailand's 'S-curve' economic strategy (Jones and Pimdee, 2017), namely robotics, aviation and logistics, biofuel and biochemical, digital industry and medical services. Second, and equally important, the infrastructure project of US$ 45 billion, known as the Eastern Economic Corridor, was crucial in enhancing investment and productivity levels in specific high-value industries. This initiative was placed at the centre of the development strategy, and was facilitated by the Thailand Board of Investments, an agency that acted under the prime minister's authority and designed a series of fiscal incentives at the corporate level. For example, income tax exemption was provided for:

- 8 years without a cap for software development and services provision, R&D, engineering design, scientific laboratories and calibration services.

[9] https://documents1.worldbank.org/curated/en/437841530850260057/pdf/Thailand-Economic-Monitor-Digital-Transformation.pdf

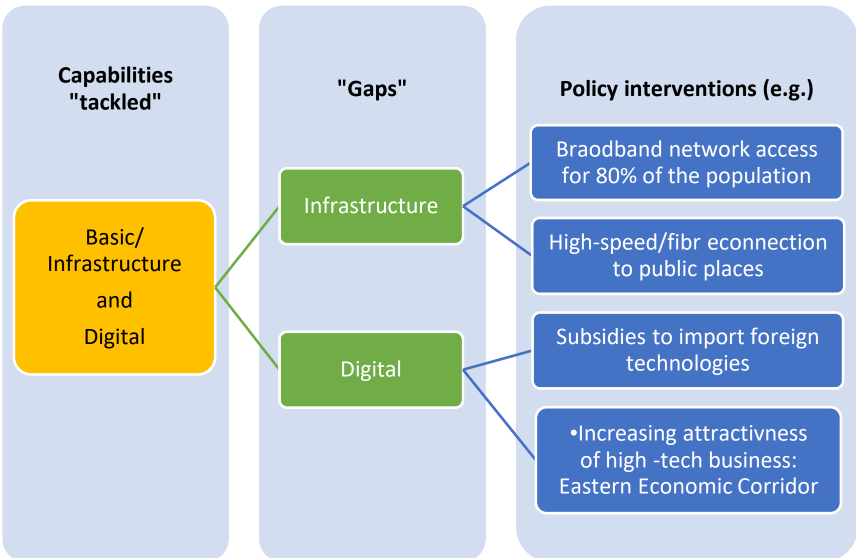
- 8 years for automation machinery and/or automation equipment industries with engineering design.
- 5 years for the assembly of robots or automation equipment and/or automation parts.

Exemptions of import duty on raw or essential materials and machinery used in manufacturing products was granted for these three groups to prioritize the manufacturing of technology. This created a highly favourable environment to invest in and trade production technologies and parts thereof. Thailand introduced a series of measures in DPTs trade to become a hub for robotic use and manufacturing in the region, with the most important measure being the US$ 6 billion Robotics Development Plan of 2017. A robotic ecosystem was established as a direct result of demand side policies that stimulated demand for automation and robots (such as a 50 per cent double tax deduction, a 200 per cent deduction for training costs as well as a credit line for buying automation), and supply side policies such as robotic suppliers' capabilities transfer mechanisms, the Centre of Robotic Excellence that supports certification, prototyping and the development of human resources) (Andreoni, 2020b).

Box 11. Robotics policies and education

Education level: From primary school to university level education incentives were designed to boost knowledge and skills in advanced technologies. For example, camps dedicated to robotics for10-year old children who are trained in building their own robots, or the King Mongkut's University of Technology, Thonburi, which offers undergraduate and graduate programmes in robotics and automation engineering, which seamlessly integrates knowledge in mechanics, electronics, and computers through project-based learning. The Centre of Robotic Excellence (CoRE) was established as a supporting agency for staff development and for upgrading automation and robotization technology to accomplish complex robot production. For a review of the challenges faced by the government in upskilling the workforce, see Puriwat and Tripopsakul, 2020).

Figure 56. Summary Thailand



4.5 Digital policy case study: Malaysia

Table 5. Malaysian Dashboard

Indicator	Measure	Year	LMICs average	UMICs average	Steepness	Malaysia
Energy availability	Electricity consumption per capita	2019	901.5	2749.5	13.2	✓5096.5
Energy reliability	Percentage of firms experiencing electrical outages	2017	65.4	55.6	0.8	✓18.9
Access to digital connectivity	Fixed broadband subscriptions per 100 people	2019;2018	4.1	13.7	22.1	!9.3
Quality of connectivity	Mean download speed (Mbps)	2020	6.0	12.4	3.7	✓46.8
Productive investments	Share of GFCF % GDP	2017-2018	25.7	21.8	1.0	✓24.2
Productive skills	Mean years of schooling	2017-2018	7.5	9.8	3.4	-
Operational efficiency	ISO 9001 certificates	2019	0.027	0.238	3.3	!0.033
Technology absorption	Intellectual Property Right payments (royalties) per GDP	2018-2019	0.001	0.003	14.5	✓0.006
Specialised skills	Percentage of graduates from STEM programmes in tertiary education	2019; 2018	24.2	20.6	1.3	✓39.2
Advanced skills	Gross enrolment ratio in tertiary education	2019; 2018	23.3	50.6	4.0	!43.1
Research effort	Gross Expenditure in R&D as a % of GDP	2018; 2017	0.3	0.6	2.2	✓1.0
Research output	Scientific and technical journal articles per million people	2018	44.7	166.6	24.1	✓750.5
Innovation output (patents)	Total patents in force per 100 bi USD GDP	2019	648.7	3149.5	30.9	!2099.9
Innovation output (royalties)	Intellectual Property Right receipts (royalties) as a % of GDP	2020;2019	182.1	459.2	3.6	✓687.7
Absorption and exposure to production technologies with digital potential	Imports of production technologies as a share of GDP	2018	0.0713	0.064	1.6	✓0.24
Deployment and adaptation of digital production technologies	Imports of digital products as a share of GDP	2018	0.0237	0.0241	2.4	✓0.16
Industrial competitiveness in digital technologies	Exports of digital products as a share of GDP	2018	1.54%	1.30%	28.0	✓23.44%

Another interesting trajectory in the Southeast Asian region is the rapid industrialization of Malaysia, which managed to upgrade its socio-economic structure, focussing on digitalization policies to escape the middle-income trap (Paus, 2017). Malaysia's success in digitalization capabilities is connected with its industrialization trajectory, which took off with the introduction of export-oriented industrial policies starting in the 1970s. The country's focus on processing industries such as rubber and high-end manufacturing industries such as electronics and automotive were key to fostering productive and organizational capabilities in production technologies. The mastering of specific production technologies and the rising levels of interconnections and complementarities in key sectors within Southeast Asian economies have led to the establishment of sound foundations for developing digital production capabilities. Malaysia's heatmap dashboard presented in **Table 5** reveals that Malaysia is one of the best performing developing countries in nearly all set of indicators. The country is particularly successful in infrastructure, innovation and digitalization capabilities. This section considers Malaysia's performance in innovation capabilities looking at the indicator "specialized skills", and digitalization capabilities focussing on the indicator "*absorption and exposure to production technologies with digital potential*".

Innovation capabilities – specialized skills

Looking back at the historical development of STEM Education in Malaysia, it is evident that Malaysia recognized STEM as a crucial component of its development and economic prosperity as early as in the 1970s, integrating science both at the government and community level as the key to economic prosperity and future survival (Thomas and Watters, 2015).

The Ministry of Education's (MOE) most recent efforts to promote STEM disciplines[10] are reflected in Malaysia's Education Blueprint 2013–2025, an initiative to strengthen STEM education. The objective is to modify the existing curriculum to the Standard Secondary School Curriculum which introduces STEM into different layers of Malaysia's education system. A quantitative objective set by the government is the 60:40 policy, which aims for 60 per cent of students to be enrolled in STEM by 2025 (Rambli and Awang, 2020). Although the policy has been used as a basis for planning students' enrolment, infrastructure preparation, teachers' training, etc., the goal of achieving a 60:40 ratio has not yet been reached. Only around 43 per cent (in 2019[11]) of students in upper secondary schools are enrolled in STEM fields for different reasons. Several studies have investigated the challenges and obstacles related to the main issues in both the student factor (e.g. motivation, interest, self-confidence) and the teacher factor (e.g. teacher preparation and up-to-date science lab and other infrastructures). This notwithstanding, MOE continues to pursue a policy that aims to contribute to a high supply of STEM workers to Malaysian industries (Shahali et al., 2017).

At the practical education level, STEM subjects are integrated into various educational stages:

(i) preschool,

(ii) primary and secondary school, and

(iii) pre-university/ upper secondary schools.

1. The National Preschool Curriculum includes an emphasis on STEM with a focus on the acquisition of basic STEM skills through early mathematics and early science, for instance (through thematic-, play-based- and inquiry-based learning).
2. The core science curricula are compulsory for all students in primary and secondary school, and scientific attitudes and values are instilled with the use of experiential learning either through spontaneous or planned activities. These attitudes, together with scientific knowledge and skills, are used in the process of scientific investigation and the implementation of projects. Mathematics teachers are encouraged to present students with routine and non-routine problems and integrate the use of ICT in mathematics teaching and learning.
3. Upper secondary school. There is a mix of elective and core subjects and STEM stream students take an average of five STEM subjects and spend 15 hours per week studying them.

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[10] See Shahali et al. (2017) for a study on the concept of STEM in Malaysia.

[11] Ramli and Awang, 2020.

Table 6. Aspects of STEM under MEB

Wave	Focus
Wave 1 (2013–2015): Strengthening the foundations	• Raising students' interest through new learning approaches and an enhanced curriculum emphasizing higher order thinking Sharpening skills and abilities of teachers • Building public and student awareness • Enabling high performing teachers and school leaders
Wave 2 (2016–2020): Building on the foundations of Wave 1	• Rolling out the new primary and secondary schools curriculum (KSSM and Revised KSSR curriculum) • Encourage development of inter-school learning communities • Upgrade existing science equipment and facilities in schools to ensure that they are optimal for effective teaching and learning of STEM • Extension of STEM awareness programmes, to primary school students and parents • 50% reduction in the urban-rural students' achievement gap, 25% reduction in the socio-economic and gender students' achievement gap
Wave 3 (2021–2025): Innovating to the next level	• Introduce fresh initiatives and programmes based on the success of the first two Waves and develop a roadmap for the future • Maintain or improve on 50% reduction in the urban rural, socio-economic and gender students' achievement gap

Source*:* Shahali et al., 2017

Malaysia's approach acknowledges that a new curriculum is only meaningful if it is in line with students' readiness to master knowledge in science. Interest in STEM needs to therefore be stimulated and organized; the government has acknowledged that this approach needs to be comprehensively translated into teaching and learning (Razali et al., 2020; Li et al., 2020). It has been translated into three main channels as part of the action plan with three main objectives:

1. Stimulate students' interest in STEM through a formal and informal approach to learning; to monitor and improve this goal, MOE designed a STEM students index for students below the age of 17 years old.
2. Sharpen teachers' knowledge and skills in STEM-related subjects through continuous professional development programmes; this was achieved by establishing links and learning projects with teachers in Taipei.
3. Increase awareness and the acculturation in STEM among students, teachers and the community through STEM programmes. Research studies report the important role of mass media in creating awareness for Thai students (Chong, 2019*;* Ishikawa *et al*., 2013).

Digitalization capabilities – absorption and exposure to production technologies

Malaysia's adoption and use of production technologies can be attributed to the country's focus industrial development, particularly in manufacturing and specific high-end sectors since the 1970s. A strong focus on specific sectors, such as electronics, resulted in the establishment of local production systems in semiconductor and electronic components (Rasiah, 2010). These sectors are crucial role in developing productive capabilities. Through a combination of demand and supply policies, the country has managed to become the world's largest exporter of semiconductors and one of the largest exporters of disk drives, telecommunications apparatus, audio equipment, room air conditioners and calculators. Multinational companies affiliated with these sectors have played a crucial role in this regard (Andreoni, 2020; Athurkorala & Menon, 1999). The development of such technologies is crucial for importing production technologies with digital potential. This stems from the deepening of industrial development and the need to import more technologies as demand increases.

One of the most recent policy programmes that has proven essential for the continuous innovation and development of high-end manufacturing production is the Third Industrial Master Plan, a broad planning blueprint for Malaysia's economic strategy from 2006 to 2020. The Ministry of International Trade and Industry (MITI) identified crucial sectors to target, such as electrical and electronics, medical devices, textiles and apparel, machinery and equipment, metals and transport equipment industries, pharmaceuticals and transport equipment. In addition, important measures were taken to foster the country's participation in digital technologies, resulting in a very high level of robot adoption, especially in plastic and chemical products (see Andreoni, 2020 for focus on robotization).

A series of policies was implemented on both the demand and supply side. One such policy is the *Domestic Investment Strategic Fund* (DISF), which was introduced in 2012 and is set to last until 2020. The DISF aims to accelerate the transition of Malaysian-owned companies to industries that are higher value-added, high-technology, knowledge-intensive and innovation-based. DISF provides a 50% grant to companies' investments (proportional to the investment) for expenditure incurred in:

(i) R&D activities carried out in Malaysia;

(ii) training of Malaysian nationals;

(iii) modernizing/upgrading of facilities and equipment;

(iv) licensing or purchasing of new/high-technology; and

(v) obtaining international standards/certifications.

Second, focussing on the transformation in labour-intensive manufacturing sectors, such as rubber, plastic and wood, the government introduced the *Automation Capital Allowance* in 2015. For high labour-intensive industries, the government offers an automation capital allowance of 200 per cent for the first RM 4 million expenditure incurred within five years of assessment (from 2015 to 2020). In Thrust 6 (Re-engineering Economic Growth for Greater Prosperity) of the Eleventh Malaysian Plan, the government emphasizes the importance of enhancing productivity through automation and focuses on five key industries in which this automation-driven re-engineering must take place. The five industries are divided into two groups:

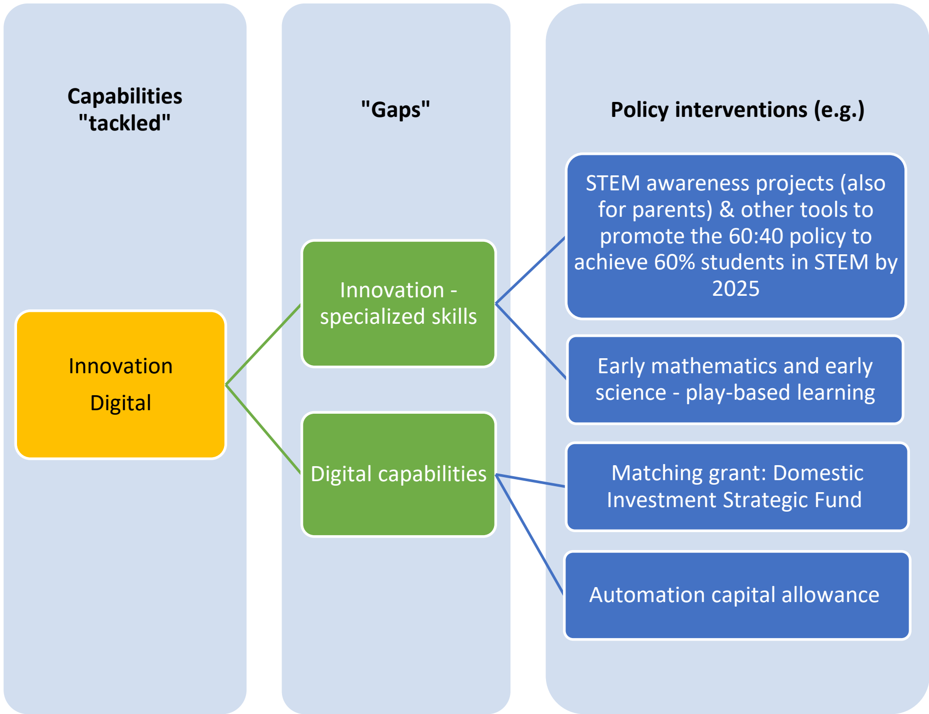
i) catalytic sectors: electrical and electronics, chemical, machinery, and equipment

ii) sectors with high growth potential: medical devices and aerospace.

Companies are also encouraged to adopt new manufacturing technologies by offering targeted incentives linked to specific outcomes and other innovative financial products and services. With the national budgets 2018 and 2019, the Domestic Investment Strategic Fund (DISF) scope was expanded to cover Industry 4.0-relevant activities (with a proposed reimbursable basis ratio of 60:40). Similarly, the High Impact Fund (HIF) was expanded to cover modernization activities for Industry 4.0. In addition, traditional matching grants and capital allowance instruments have been scaled up and made even more targeted. These include an accelerated capital allowance of 200 per cent on the first RM 10 million for manufacturing and manufacturing-related services and the capital allowance for ICT equipment and software. The latter scheme only recognizes expenditures incurred for the purchase of

ICT equipment and computer software packages to develop customized software comprising consultation, licensing and incidental fees related to software development.

Figure 57. Summary Malaysia



4.6 Digital policy case study: South Africa

Table 7. South African dashboard

Indicator	Measure	Year	LMICs average	UMICs average	Steepness	South Africa
Energy availability	Electricity consumption per capita	2019	901.5	2749.5	13.2	4008.9
Energy reliability	Percentage of firms experiencing electrical outages	2017	65.4	55.6	0.8	92.0
Access to digital connectivity	Fixed broadband subscriptions per 100 people	2019;2018	4.1	13.7	22.1	2.1
Quality of connectivity	Mean download speed (Mbps)	2020	6.0	12.4	3.7	14.0
Productive investments	Share of GFCF % GDP	2017-2018	25.7	21.8	1.0	18.2
Productive skills	Mean years of schooling	2017-2018	7.5	9.8	3.4	10.1
Operational efficiency	ISO 9001 certificates	2019	0.027	0.238	3.3	0.004
Technology absorption	Intellectual Property Right payments (royalties) per GDP	2018-2019	0.001	0.003	14.5	0.005
Specialised skills	Percentage of graduates from STEM programmes in tertiary education	2019; 2018	24.2	20.6	1.3	18.3
Advanced skills	Gross enrolment ratio in tertiary education	2019; 2018	23.3	50.6	4.0	23.8
Research effort	Gross Expenditure in R&D as a % of GDP	2018; 2017	0.3	0.6	2.2	0.8
Research output	Scientific and technical journal articles per million people	2018	44.7	166.6	24.1	225.1
Innovation output (patents)	Total patents in force per 100 bi USD GDP	2019	648.7	3149.5	30.9	4281.1
Innovation output (royalties)	Intellectual Property Right receipts (royalties) as a % of GDP	2020;2019	182.1	459.2	3.6	324.6
Absorption and exposure to production technologies with digital potential	Imports of production technologies as a share of GDP	2018	0.0713	0.064	1.6	0.05
Deployment and adaptation of digital production technologies	Imports of digital products as a share of GDP	2018	0.0237	0.0241	2.4	0.02
Industrial competitiveness in digital technologies	Exports of digital products as a share of GDP	2018	1.54%	1.30%	28.0	0.33%

South Africa is a fast-growing economy that was part of the 'boom' that both BRICS and—albeit to a lesser extent—resource rich countries experienced at the beginning of the century. Despite its abundance of primary commodities, South Africa has also pursued industrial policies to shift away from raw materials towards manufacturing. Among the sectors specifically targeted are the automotive and plastic industries and machinery equipment for mining. The heatmap dashboard presented in Table 7 reveals some structural problems in South Africa's economy, such as electrical outages – the World Bank country survey reports that 92 per cent of firms experienced electrical outages. The country also exhibits some strengths at the national level. For example, South Africa performs well in innovation capabilities, with a positive feedback loop between expenditure in R&D, scientific articles and total patents, with the country performing above its reference group's average. The indicators on digital capabilities, where South Africa performs below the UMICs' average, suggest that the country still needs to improve commercialization and technological scaling up, bringing innovations to the shopfloor level. This section discusses the government's efforts in creating positive feedback loops for innovation capabilities, looking at the indicators "research effort" and "research output".

Innovation capabilities: From R&D to university journals and patents

South Africa has been the fastest growing country in Africa, yet significant issues need to be addressed, such as the persistent inequality, which has resurfaced after a decline in the 1990s around 2005–2006, and the high unemployment rate, especially among young people. The country's economic and innovation-related structure underwent a transformation in 1995 after 20 years of low GDP growth, with income per capita stagnating at levels similar to those in the 1960s. The first democratic government, faced with the challenging task of completely overhauling the system, prioritized scientific, technological, and innovative efforts that redesigned the national innovation systems (NIS) (Cassiolato and Vitorino, 2011).

The efforts related to the governance of science, technology and innovation (which falls under the Department of Science and Technology (DST) and the Department of Trade and Industry (DTI)) have three main components (OECD, 2007):

1. Commitment to research, development, engineering and innovation with a focus on defence and closely monitored by the central government.
2. Commitment to promoting innovation in mining and related industries, including the aim to establish state enterprises such as Sasol and Eskom in the key sectors chemical energy and electricity.
3. Commitment to providing technological support for large-scale and resource-intensive agriculture.

These commitments were reflected in the creation of numerous agencies that emerged from DST. Together with DTI, they provided financial support for various innovative interactive activities involving universities, science councils and business enterprises. Examples include the introduction of the Innovation Fund and the Technology and Human Resources for Industry Programme (THRIP) which aims to facilitate the participation of higher education and science council researchers in industrial innovation and technological adaptation (Cassiolato and Vitorino, 2011). More specifically, THRIP is a private-public collaboration based on a cost-sharing grant of up to R 8 million annually for a period of three years for projects related to applied R&D in science, engineering and technology. It was established in 1992, and is considered one of the most successful supply-side initiatives of DTI (Skeef, 2002). Another crucial public research institution, and the largest in the country, is the Council for Scientific and Industrial Research, which has over 3,000 researchers/expert and accounts for nearly 10 per cent of public R&D.

In 2007, DST proposed a 10-year plan to promote a knowledge-based economy driven by four elements: human capital development, R&D for knowledge generation, knowledge infrastructure, and enablers to favour the link between research results and socioeconomic outcomes.[12] One important supply policy, which continues to be in place, is a tax concession with a deduction of up to 150 per cent on income if R&D expenditure and an accelerated depreciation deduction for capital expenditure incurred on machinery or plants used for R&D[13] (Section 11D of the Ime Tax Act). The innovation system is generally concentrated in state organizations and in large private companies. Private

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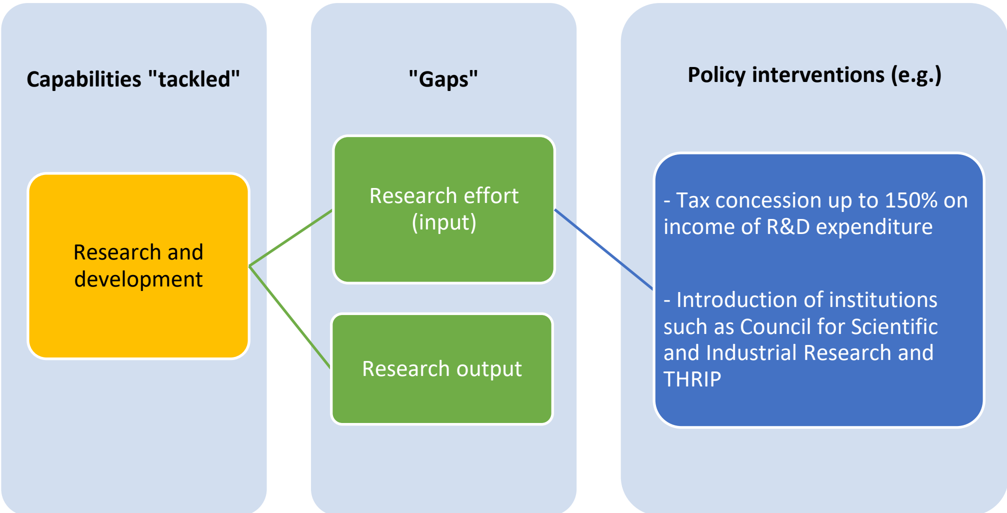
[12] https://www.sansa.org.za/wp-content/uploads/2018/05/DST-Ten-Year-Innovation-Plan.pdf

[13] Numerous R&D centres have been established, especially for these sectors, such as mining, where the government has been playing a key role in fostering innovation. Some examples are: SAMERDI, CSIR, Mandela Mining Precinct.

research institutes complement universities' innovation system, with a high share of business R&D focused on resource-intensive industries and related activities along the value chain, and on information technology.

Despite the country's generally positive trajectory, the aim of reaching 1 per cent of GDP in R&D expenditure was not reached. South Africa saw a decline of 5 per cent (R 1,941 billion) in R&D expenditure in 2019, from R 38,725 billion in 2017/18, after seven consecutive years of growth. While this decrease was insufficient to offset reductions in government and business R&D expenditure, there was a modest increase in R&D expenditure by the higher education sector, amounting to R 173 million (1.3 per cent), and by the non-profit sector of R 269 million (22.1 per cent)[14].

Figure 58. Summary South Africa



[14] https://sciencebusiness.net/network-updates/south-african-investment-rd-declines-vital-era-covid-19

4.7 Digital policy case study: Brazil

Table 8. Brazilian dashboard

Indicator	Measure	Year	LMICs average	UMICs average	Steepness	Brazil
Energy availability	Electricity consumption per capita	2019	901.5	2749.5	13.2	2915.7
Energy reliability	Percentage of firms experiencing electrical outages	2017	65.4	55.6	0.8	45.8
Access to digital connectivity	Fixed broadband subscriptions per 100 people	2019;2018	4.1	13.7	22.1	15.6
Quality of connectivity	Mean download speed (Mbps)	2020	6.0	12.4	3.7	17.9
Productive investments	Share of GFCF % GDP	2017-2018	25.7	21.8	1.0	15.1
Productive skills	Mean years of schooling	2017-2018	7.5	9.8	3.4	8.0
Operational efficiency	ISO 9001 certificates	2019	0.027	0.238	3.3	0.091
Technology absorption	Intellectual Property Right payments (royalties) per GDP	2018-2019	0.001	0.003	14.5	0.003
Specialised skills	Percentage of graduates from STEM programmes in tertiary education	2019; 2018	24.2	20.6	1.3	18.4
Advanced skills	Gross enrolment ratio in tertiary education	2019; 2018	23.3	50.6	4.0	53.3
Research effort	Gross Expenditure in R&D as a % of GDP	2018; 2017	0.3	0.6	2.2	1.2
Research output	Scientific and technical journal articles per million people	2018	44.7	166.6	24.1	287.1
Innovation output (patents)	Total patents in force per 100 bi USD GDP	2019	648.7	3149.5	30.9	687.8
Innovation output (royalties)	Intellectual Property Right receipts (royalties) as a % of GDP	2020;2019	182.1	459.2	3.6	439.0
Absorption and exposure to production technologies with digital potential	Imports of production technologies as a share of GDP	2018	0.0713	0.064	1.6	0.02
Deployment and adaptation of digital production technologies	Imports of digital products as a share of GDP	2018	0.0237	0.0241	2.4	0.01
Industrial competitiveness in digital technologies	Exports of digital products as a share of GDP	2018	1.54%	1.30%	28.0	0.08%

After promising socio-economic developments at the beginning of the 2000s, with a favourable commodity cycle and the implementation of numerous policies to foster manufacturing development, expectations were high for Brazil's economy to continue growing. However, over the past two decades, the Brazil's rapid deindustrialization trajectory created a series of bottlenecks, resulting in the country's inability to upgrade its overall productive structure towards a more digitalized one. As presented in **Table 8**, Brazil's performance in all infrastructure indicators is exceptional, as expected from a country at a relatively high stage of development. Conversely, the country's performance in production indicators is weak, lagging behind UMICs in the three indicators with the orange sign and even below LMICs in terms of the share of GFCF as a percentage of GDP. Brazil shows strong innovation capabilities in nearly all indicators apart from STEM graduates, confirmed by a high share of R&D expenditure compared with countries at a similar stage of development and a very high volume of scientific and technical journal articles. Lastly, Brazil performs poorly in the last layer of digitalization capabilities due to its lower share of production and digital technologies imports as a share of GDP. This case study briefly discusses the difficulties Brazil faces in translating innovation into productive capabilities that are spread throughout the overall economic system and its resulting inability to provide effective digitalization policies.

Digital capabilities: Difference between discourse and practice

The Brazilian government's digital strategy[15]includes a series of interesting proposals and objectives, yet it has faced difficulties translating these into practical commitments. The main challenge lies in the disparity between policy documents and the actions taken by government organizations and institutions.

The Brazilian economy has significant capabilities and lies at the frontier of innovation in certain "islands of productive excellence" such as aviation, agriculture and health (Mazzucato and Penna, 2016). However, although Brazil has experienced a strong deindustrialization trend in the past two decades, it has also witnessed continuous underperformance in innovation activities that have not resulted in productivity gains, increased competitiveness and better integration into GVCs.

the ICT sector plays a crucial role in the digitalization strategy, which lags behind leading sectors in terms of innovation output. For example, only 10 per cent ICT patents were registered between 2013 and 2016 compared to around one-third in OECD countries and 60 per cent in China (OECD, 2020). One of the policies in place, which however did not translate into economic innovation, is the establishment of the National Fund for Scientific and Technological Development, which is primarily financed from sectoral funds, including one specifically for ICT. These funds were established in the 1990s to provide more stable financing for scientific and technological development, and serve as the primary source of R&D funding for public or non-profit organizations and enterprises. In addition, there are a several funding mechanisms for research and industrial innovation that support the creation of linkages between firms and research centres, such as the Ministry of Science, Innovation and Communications—the main actor providing support for R&D—and the Ministry of Education. Another interesting example of the difficulties Brazil is facing in industrial R&D is the recent shift in the country's policy, which moved away from the historical tradition of direct support for R&D towards a reliance on tax relief (Colombo, 2016). However, the number of applicants has been extremely low, with only 1,476 firms applying for the incentive in 2017, which is just 2 per cent of potentially eligible firms (OECD, 2020).

Brazil's research output performance is outstanding, with an upswing in the number of researchers that has resulted in a steady growth in the country's scientific output, securing the 11th position worldwide in terms of scientific publications. However, this success has not been reflected in improvements in patenting activities, except in those islands of high productive capabilities such as aerospace and agroindustry, with the consequent inability to transfer knowledge from university and research centres into applied innovations (OECD, 2020). It is noteworthy that high-rate researchers tend to remain in academia and government in Brazil contrary to other OCED countries where they actively contribute to R&D in the private sector. This can be attributed to the lack of demand and salary competition (Mazzucato and Penna, 2016).

Recently, funding for basic research has been decreasing. This, together with the lack of strategies on digitalization aspects, such as AI and robotics, has failed to provide a comprehensive strategy for boosting domestic supply capabilities and demand-side initiatives to encourage more students to pursue STEM disciplines (confirmed by the poor performance in this indicator reported in our dashboard).

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[15] https://www.gov.br/mcti/pt-br/centrais-de-conteudo/comunicados-mcti/estrategia-digital-brasileira/estrategiadigital.pdf

5 Links to other EQuIP tools

Other EQuIP tools either share some indicators with the present tool, can be combined for additional insights or cover topics that are thematically connected to the present tool.

Tools 8 and 1 – Productivity and Structural Change

Firms' capabilities eventually translate into output and importantly, help determine their productivity. As such, increasing capabilities, including digital capabilities, boost productivity. Moreover, improved capabilities allow firms to carry out more advanced tasks capturing higher value added, i.e. within-manufacturing structural change. Both structural change and productivity are topics discussed in depth in Tool 1.

Tools 8 and 2 – Trade

Some indicators in the present tool use trade data to measure digital capabilities. Tool 2 focuses on trade and trade data in more detail; however, it uses trade data in different classifications.

Tools 8 and 3 – Diversification and Upgrading

Tool 3 focuses on measuring diversification and upgrading in both production and trade. While there are fewer indicator connections to this digital tool, an increase in different capabilities is an ingredient for upgrading production and, ultimately, diversifying a firm's and country's production and trade structure.

Tools 8 and 4 – Digitalization and Global Value Chains

Tool 4 on global value chains focuses on relevant data for analysing various aspects of value chains. It also highlights that services are an integral part of value chains. The tool can be used in connection with the products identified by the technology classification developed in the present tool. This is in part already shown in Section 0.

Tools 8 and 5 – Employment and Skills

The use of new digital production technologies creates new jobs and requires new types of skills. Tool 5 on employment and wages discusses labour market-related aspects that can be the result of digitalization or represent bottlenecks to digitalization. It shares some indicators with the present tools.

Tools 8 and 6 – Digitalization and Gender Aspects

Similar to Tool 5, Tool 6 on gender mainstreaming in industry addresses many socioeconomic aspects with a focus on differences between sexes. As such, it provides an additional perspective on the connection to employment, income and skills.

Tools 8 and 7 – Digitalization and the Environment

Increasing capabilities might enable firms to engage in more environmentally friendly production. Tool 7 introduces many indicators to measure production and resource use, waste generation, pollution and other related aspects.

6 Possible extensions

Sectoral applications of ADP technologies

The study of readiness for digitalization at the sectoral level is problematic because of the lack of data. Nevertheless, a better understanding of foundational capabilities and the distinction between ADP technologies can still be valuable in guiding more granular analyses in countries where such information is available. Arguably, it might be of interest to examine the extent of ADP technology adoption across sectors, together with their practical application in the productive process and other relevant activities at the level of firms.

Opportunities for developing production and innovation capabilities, which are foundational for digitalization, are widespread across sectors, yet some sectors offer more learning opportunities than others. This means that the pathways to capability development vary not only in terms of the country's level of development, but also its sectoral structure of production. The applications of ADP technologies in different productive sectors differ considerably and require distinct capabilities. **Table** 9 presents this heterogeneity in the potential opportunities and necessary capabilities. It provides examples of applications of ADP technologies in ten industrial sectors, organized according to their required level of capabilities, either basic/intermediate capabilities or advanced capabilities. This provides insights for countries seeking to digitalize, based on their existing sectors and existing level of capabilities. While countries can adopt more ambitious strategies to explore the development of new sectors enabled by ADP technologies.

Table 9 documents that the opportunities created by ADP technologies are not necessarily limited to high-tech sectors. In fact, sectors that usually play a leading role in developing countries, such as agriculture and agroindustry, consumer goods such as textiles and garments, and basic inputs may also offer opportunities for upgrading through digitalization. Digitalization dividends can be achieved in these sectors with a basic/intermediate level of capabilities, although the largest returns lie in applications that require advanced capabilities. It is worth noting that some sectors are mainly users of ADP technologies (demand pull), such as agroindustry, consumer goods, chemicals, pharmaceuticals, while others are suppliers (technology-push), such as capital goods, and ICTs.

Table 9. Applications of ADP technologies in ten different sectors based on type of capabilities required

	Type of capabilities required	Aerospace and defence	Agroindustry	Automotive	Basic inputs	Capital goods
Technology fusion	Basic/intermediary	- Digitalization of machines and processes for monitoring, tracing parts and components, identification of trends and anomalies, predictive maintenance and optimization of aircraft production, and logistics enabled by IoT, AI and network technologies.	- Precision agriculture sensors for monitoring of various conditions: water levels, soil, weather, plant and herd health, aerial images from drones and satellites, and capital goods performance; - Automatic responses, such as intelligent irrigation systems and adaptations to meteorological conditions; - Predictive maintenance of tractors and equipment; - Traceability of products with electronic tags, real-time control of operations, and optimization of logistics of the supply chain, storage and distribution; - Increasing use of online commercialization platforms enabling demand monitoring in real time.	- Digitalization of machines and processes for monitoring, tracing parts and components, identification of trends and anomalies, predictive maintenance and optimization of automobile production and logistics with connected sensors, AI algorithms and network technologies; - Product development through virtualization technologies.	- Identification of anomalies in equipment and predictive maintenance; - Traceability of products and components; - Improved quality Control (e.g. detecting surface defects), reducing waste; - Reducing ramp-up time; - Intelligent interconnection of the business chain (logistics, stock, supplies, distribution); - Enhanced stock management; - Commercialization platforms with real-time monitoring of requests; - Virtualization of business management systems.	- Identification of anomalies and predictive maintenance; - Improved quality and process control; - Product development through virtualization technologies; - Intelligent interconnection of the business chain (logistics, stock, supplies, distribution); - Virtualization of business management systems; - Traceability of products and components.
	Advanced	- New aircraft projects such as the 'hybrid aircraft': combination of advanced materials (new metallic alloys, nanostructured composites), high complexity components produced with 3D printing, hybrid propulsion systems combining conventional or gas propulsion and electric propulsion, embedded digital technologies enabling detailed monitoring and optimal control of aircraft performance, and optimized operation and services (aircraft health management, automation and optimization of take-off, single pilot operation, etc.). - Drones (Unmanned aerial vehicle (UAVs)): increasingly autonomous and collaborative, drones have a potential of application in several markets, such as defence (security and monitoring), civil (transport and delivery of cargo) or recreational. Developments within this		- Connected car (short-term) and autonomous cars; - (Long-term): convergence of advanced sensors (produced with nanotechnology), new battery technologies, AI algorithms and communication networks, with parts produced with 3D printing; - Electric (or hybrid) car.		- Connected devices and machines with own processing and analytics capacity (agricultural machinery, machine tools, engines, etc.); - Key machinery to enable smart and connected production.

		sector can lead to a new segment of urban autonomous aerial vehicles used for transportation within large cities. New miniaturized satellites that can operate in swarms. Relatedly, new launching vehicles for miniaturized satellites.				
Artificial intelligence, data analytics and cloud computing	Basic/intermediary	- Data-analytics of aircrafts and embedded systems; - Man-machine interface for pilots and passengers.				
	Advanced	- Enhanced image recognition and treatment for navigation, target recognition for smart weapons, earth-monitoring satellites and biometric systems used as security keys: - Autonomous piloting (for weapons, drones and aircraft); - AI for command, control, communication and information systems (C3IS). E.g. air traffic control; - In the space segment, incremental advances amplify the capacity of current platforms and satellites, especially the volume of data transmission using existing communication satellites.	- Deep learning for precision agriculture; - Machine learning in production; - Facial and body recognition of animals, allowing for health monitoring of cattle; - Machine learning in retail: creating personalized products and diets.	- Advanced driving assistance systems (ADAS); - Improved man-machine interface (e.g. voice commands); - Support of information entertainment ("infotainment").		- AI for autonomous machine-tools, robots, vehicles, electric equipment of the smart-grid, etc.
Robotics, CPS and additive manufacturing	Basic/intermediary		- Business intelligence tools applied to agriculture; - Autonomous platforms for precision agriculture; - Robots and drones for use in agriculture and for obtaining data of the farm.		- Robotics for enhancing work safety. For example, metal baths can be carried out by robots.	
	Advanced	- 3D printing for complex aircraft components; - 3D printing for prototyping (e.g. Airbus THOR mini aircraft); - Robotics for larger-scale productive units, especially in the passenger aircraft segment; - Robots in military (robots for security and defence missions) and civilian applications (co-pilot bots).	- Robots for classification of plant seedlings according to its growth potential.	- Advances in smart robotics in the assembly line.	- Supercomputers and drones with sensors capable of elaborating 3D maps of natural resources in real time.	- More precise, faster, smaller scale, more energy efficient 3D printers that can operate with different materials; - Autonomous and collaborative robots.
	Basic/intermediary	- Use of IoT in civilian aviation:	- Optimization of the use of inputs, defensives and seeds;			

IoT and network technologies		fuel, engine and system monitoring, aircraft tracing, baggage smart tagging, passenger identification token.	- Optimization of environmental management and use of resources (energy, water, soil); - Blockchain and QR technology for client relationships. - Data collection, integration and coordination through wireless networks; - Mesh networking and hop networking systems with the use of digital stations that function with repeaters.			
	Advanced	- Use of IoT in military aviation: integration of C3IS systems with intelligent weapons and air platforms; - Optic fibres in aircraft command systems; - Systems of civilian and military C3IS systems: higher capacity and security (advances in cryptography).	- Stock optimization with the adjustment of production to demand (including changing crops in response to changes in consumption trends).	- Protocol of wireless communication between vehicles (vehicle-to-vehicle (V2V)) aimed at avoiding collisions.		- New demand of energy from external sources (energy harvesting) from IoT implies the development of specific generation, transmission and distribution (GTD) equipment; - Generalization of the use of wireless communication protocols in machines and equipment; - Equipment compatible with the means and protocols of the "smart grid".
	Type of capabilities required	Chemicals	Consumer goods	ICTs	Oil and gas	Pharmaceuticals
Technology fusion	Basic/intermediary	- Identification of anomalies and predictive maintenance; - Reduce energy consumption; - Enhance health, security and environmental (HSE) management; - Intelligent interconnection of the business chain (logistics, stock, supplies, distribution); - Improving processes of decision-making with data; - Electronic sales platforms; - Continued connection to the product after sale -trend of servitization (e.g. instead of selling products, selling services of water treatment, soil fertilizing, crop defence, catalysing, etc.).	- Identification of anomalies and predictive maintenance; - Virtualization of business management systems; - Traceability of products and components; - Intelligent interconnection of the business chain (logistics, stock, supplies, distribution).	- Identification of anomalies and predictive maintenance; - Intelligent interconnection of the business chain (logistics, stock, supplies, distribution); - Virtualization of business management systems; - Traceability of products and Components.	- Identification of anomalies and predictive maintenance of wells and drills; - In refining, optimization and control of flux in real time under uncertainty; - Intelligent interconnection of the business chain (logistics, stock, supplies, distribution); - Virtualization of business management systems; - Traceability of products and components.	- Identification of anomalies and predictive maintenance; - Intelligent interconnection of the business chain (logistics, stock, supplies, distribution); - Virtualization of business management systems; - Traceability of products and components.
	Advanced	- Increase reaction yields.	- Consumer robots (e.g. for the elderly and for deliveries); - Smart and connected household appliances; - Smart wearables (smart textiles, smart fabrics,	- Product development through virtualization technologies.	- Green molecular design for high value-added products; - Innovations in prospection: sensors and AI for characterization of reservoirs (transformation of data in 3D images), enabling the reduction in	- Bioprocesses using genetically modified organisms (intensive in data analytics); - Applications to early stage drug discovery, including speeding-up certification processes;

			smart accessories); - Product development through virtualization technologies.		dry oil well drilling (a large source of costs in the sector).	- Precision (or personalized) medicine: Combination of genetic engineering, synthetic biology, AI and pharmacogenomics to produce drugs adapted to the genotype of the individual; - Biosensors (and biomarkers), new materials for controlled release of drugs are also necessary.
Artificial intelligence, data analytics and cloud computing	Basic/intermediary	- Patent and publications analysis in the chemical field through a personal learning network (PLN) and deep learning.	- Retail market: virtual search, personalized purchase recommendations, electronic wearables, chatbots (virtual shops); - Many applications of machine learning in productive processes of consumer goods.	- Machine learning for auto-updating of software and correction of bugs.		- Analysis of patents, genomic data and publications in the life-sciences field though PLN and deep learning.
	Advanced	- Chemical product (inputs) personalization through big data analytics; - Deep learning for new product development (also - Generative adversarial network (GAN) algorithms) to accelerate development and reduce the costs of R&D: - GAN and neural networks to test new chemical molecular entities; - Virtual models of synthetic elements.	- Incorporation of AI solutions in traditional household equipment, such as physical exercise equipment, interactive games, smart kitchen apparel with voice recognition and natural language processing (NLP).	- Development (prototyping) of software of applications of machine learning and deep learning; - Development of applications for cybersecurity, for example, in anticipating cyber attacks; - Data analytics for personalization and customization of products; - New algorithms in a language that is compatible with sensors and actuators.	- Big data analytics for prospection geological models – improved characterization of reservoirs.	- Deep learning in the development of new drugs, including GAN algorithms for accelerating development and reducing costs; - GAN and neural networks for testing new molecular entities that are candidates for new drugs; - Substitution of tradition in vitro HTS (high throughput screening) methods by total in silico screenings. Advancing in this direction, AI systems could contribute to the selection of leading compounds that create the desired genetic expression; - AI applications to image diagnosis; - Big data analytics of enormous amounts of multimodal data generated by research and diagnostic platforms, health professionals and mobile systems worldwide. This includes image, phenotypical and clinical data.
Robotics, CPS and additive manufacturing	Basic/intermediary	- Use of 3D printing in the transformation of plastics; - Impacts upstream of the productive chain, with increases in demand for specific inputs; - Demand for development of specific intermediary products; - Robots for inspection in petrochemicals;				

		- Robots for detection of leaks (improving safety in chemical and petrochemical industries).				
	Advanced		- Use of 3D printing for personalized consumer goods (e.g. Electroloom, Open Knit); - Entirely 3D printed clothes (e.g., Bikini N12, Materialise).	- Advances in smart robotics in assembly lines.	- Autonomous underwater vehicles (AUV) to assist oceanographic research and E&P of oil and gas; - Increasing use of robots for inspection, maintenance and repair (IMR) and painting procedures; - Lighter and more compact equipment with embedded electronics and intensive use of advanced materials will enable low-cost production methods; - Subsea machinery / subsea factories, whose main goal is to reduce the weight over offshore platforms.	
IoT and network technologies	Basic/intermediary	- Information derived from clients helping understand the performance of the product in use.	- Product traceability can also be important in non-durable goods (e.g. when there is a regulation in which the producer is liable for the disposal of the product).			- Connected devices for medical/hospital use (e.g. diagnostics and monitoring) and patient use (continuous monitoring with preventive diagnostic); - Traceability of products similar to the food industry; - Offering online orientations to patients in association with the medical class.
	Advanced	-	- Networks used for monitoring the product lifecycle, especially in durable household appliances, enabling new attributes to products and complementary services; - Incorporation of assistive technologies (e.g. assisting elderly people to take medication at the correct time), or washing machines with connected services of hygiene and cleaning products.	- Micro-controllers, sensors and actuators; microchips for embedded use; distributed processing capacity (cloud and fog computing); - Among sensors, those based on semiconductors MEMS (Micro-Electro-Mechanical Systems) which require techniques and materials of nanotechnology; - Network technology for local processing as well as for data transmission system on chips (SoCs) containing communication modules (generally wireless) and embedded sensors; - Increasing role of software in communication systems (Software-defined Networks – SDN; Network Function Virtualization – NFV).	- Offshore production uses networks of optic fibres to connect platforms to the shore (submarine optic cables). Long-distance communication networks compete with optic fibres in this application; - A new Interesting development are optic fibre sensors, which can detect alterations in the optic signal due to external conditions (pressure, temperature, seismic-acoustic vibrations, etc.); - Use of optic fibres in the inspection of pipelines and exploration, development and production (E&P) wells.	- Change in business models of pharmaceutical companies that become "healthcare firms"; - Use of sensors and digital services in continued treatment; - Possibility of collecting data from the field for clinical tests, monitoring of performance of medicines, as well as new forms of managing the product cycle.

Source: Andreoni, Chang and Labrunie, 2021b, based on Andreoni et al., 2021 and IEL, 2018

Different industries will play different roles in the unfolding of the 4IR; hence, industrial policy targeted at different industries must be designed accordingly. While it is widely recognized that certain industries, such as the machine tool industry, will play a key role in 'technology push', the potential of other industries in the 'demand pull' role is often overlooked. For example, applying manufacturing principles to agricultural production could deliver significant productivity gains and improved international market access. This, in turn, creates demand for a modern agricultural equipment industry. The digitalization of mining holds enormous potential and could serve as a significant demand-pull factor for the development of leading mining equipment industries in countries such as South Africa and several others in Latin America.

Following the descriptive analysis of the basic indicators of digital capabilities and how they have been constructed based on the new Digital Technology Classification (Annex), we introduce some of the more sophisticated analyses this tool offers.

First, we disaggregate our digital technology classification to consider digital production technologies, digital parts and digital instrumentation separately. We do this by intersecting our 156 products with selected chapters of the Broad Economic Categories 4 (BEC 4) classification:

- BEC 4 Chapter 41: Capital goods (except transport equipment)
- BEC 4 Chapter 42: Parts and accessories
- BEC 4 Chapter 22: Industrial supplies not elsewhere specified, processed.

Table 10 summarizes the new list of indicators that results from this disaggregated Digital Technology Classification.

Table 10. Advanced Digital Capabilities Indicators

Digital Capabilities	Dimensions	Indicators	Country coverage LMICs Tot: 135	Coverage time	Source
Import of ADPT	**Deployment and adaptation of advanced digital production (ADP) technologies**	**Import of ADP technologies** (automated and/or with embedded digital systems) Selection of HS 2017 code 84-85-90, intersected with BEC 4 code 41-42	ALL	2002 – HS02 2017 – HS17	UNCOMTRADE
> Import of ADPT final product		**Import of ADP technologies** (automated and/or with embedded digital systems) Selection of HS 2017 code 84-85, intersected with BEC 4 code 41	ALL	2002 – HS02 2017 – HS17	UNCOMTRADE
> Import of ADP parts		**Import of parts** Selection of HS 2017 code 84-85, intersected with BEC code 42	ALL	2002 – HS02 2017 – HS17	UNCOMTRADE

> Import of instrumentation for ADPT		**Import of instrumentation technologies** (measurement and other infra-technologies) Selection of HS 2017 code 90	ALL	2002 – HS02 2017 – HS17	UNCOMTRADE
Export of ADP technologies	**Industrial competitiveness in advanced digital production (ADP) technologies**	**Export of digital production technologies** (automated and/or with embedded digital systems) Selection of HS 2017 code 84-85-90, intersected with BEC 4 code 41-42	ALL	2002 – HS02 2017 – HS17	UNCOMTRADE
> Export of ADPT final product		**Export of advanced digital production technologies** (automated and/or with embedded digital systems) Selection of HS 2017 code 84-85, intersected with BEC 4 code 41	ALL	2002 – HS02 2017 – HS17	UNCOMTRADE
> Export of ADP parts		**Export of parts** Selection of HS 2017 code 84-85, intersected with BEC code 42	ALL	2002 – HS02 2017 – HS17	UNCOMTRADE
> Export of instrumentation for ADPT		**Export of instrumentation technologies** (measurement and other infra-technologies) Selection of HS 2017 code 90	ALL	2002 – HS02 2017 – HS17	UNCOMTRADE

Source: Authors

Second, we analyse the regional integration of these product sub-groups into trade, using the digital classification to conduct value chain analyses for specific regions. Trade data have been widely used to conduct value chain analyses as they allow to track import and export relationships between pairs of countries for different categories of products.

Disaggregated analysis for digital production technologies, parts and instruments

By disaggregating the classification, we find that LMICs exhibit various forms of digital specializations. For example, three of the significant outliers in the previous section – Viet Nam, Malaysia and China – heavily rely on digital parts imports (79 per cent, 78 per cent and 74 per cent, respectively). Thailand—the fourth outlier—has a slightly less pronounced reliance on digital parts imports (53 per cent), with higher DPTs imports.

On the other hand, countries such as South Africa, Paraguay, El Salvador and several small economies rely significantly on DPTs imports (over 70 per cent) – that is, ready-made machines instead of the digital parts.

Some economies, such as Belarus, Montenegro and Mongolia have a high share of digital instruments imports (18 per cent).

These differences reflect different **digital insertions** in the world economy. Some countries are buyers of ready-made products, while others import parts and instruments to be assembled and implemented in their own industries. These differences are also reflected in these countries' export performance.

Table 11. Top-20 LMICs in digital imports as a % of GDP and their import composition

Import indicator		Composition (%)		
	Total digital imports/GDP	**Digital Production Technologies**	**Digital Parts**	**Digital Instruments**
Viet Nam	23.73%	10%	79%	11%
Malaysia	15.71%	16%	78%	7%
Thailand	7.22%	36%	53%	10%
Tunisia	4.32%	31%	59%	10%
Paraguay	4.12%	76%	21%	3%
China	4.07%	14%	74%	12%
Bulgaria	3.06%	53%	34%	13%
Belarus	2.79%	56%	26%	18%
Kyrgyz Republic	2.73%	79%	12%	9%
Maldives	2.60%	70%	21%	9%
Fiji	2.56%	69%	17%	14%
Jordan	2.29%	64%	29%	7%
Rwanda	2.29%	59%	26%	15%
Serbia	2.28%	63%	22%	15%
Morocco	2.27%	40%	50%	10%
Montenegro	2.19%	65%	19%	16%
Mongolia	2.17%	62%	22%	16%
Armenia	2.16%	75%	12%	13%
South Africa	2.14%	70%	17%	12%
El Salvador	2.12%	70%	22%	8%

Heterogeneity also exists in digital products exports. Viet Nam, Thailand and China seem to be more specialized in the export of DPTs, while Malaysia specializes in the export of digital parts. Morocco and Costa Rica are also highly specialized in digital parts exports (92 per cent and 71 per cent, respectively). Finally, some countries specialize in exporting digital instruments (Belarus (49 per cent), Tunisia (29 per cent), South Africa (27 per cent), India (25 per cent) and Turkey (22 per cent). Despite being a LIC, Congo stands out, ranking among the top-20 in our export classification, with a very high level of specialization in digital instruments (93 per cent of the country's digital exports).

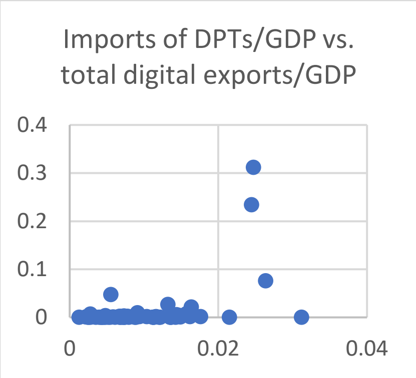
Table 12. Top-20 countries in digital exports/GDP and their export composition

Import indicator		Composition (%)		
	Total digital exports/GDP	**Digital Production Technologies**	**Digital Parts**	**Digital Instruments**
Viet Nam	31.20%	56%	39%	5%
Malaysia	23.44%	19%	74%	7%
Thailand	7.63%	51%	41%	7%
China	4.76%	58%	35%	7%
Tunisia	2.67%	21%	50%	29%
Bulgaria	2.16%	31%	53%	16%
Morocco	0.98%	5%	92%	2%
Belarus	0.78%	20%	31%	49%
Cambodia	0.67%	40%	59%	1%
Serbia	0.54%	47%	33%	20%
Jordan	0.40%	80%	10%	10%
Indonesia	0.38%	60%	33%	7%
South Africa	0.33%	44%	29%	27%
Costa Rica	0.32%	12%	71%	17%
Dominican Republic	0.29%	57%	23%	20%
Tanzania	0.24%	16%	64%	20%
Turkey	0.24%	37%	40%	22%
North Macedonia	0.24%	25%	66%	9%
India	0.21%	41%	34%	25%
Congo	0.20%	4%	3%	93%

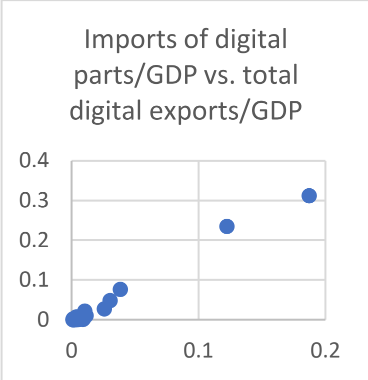
When examining the relationship between imports and exports, we observe a strong correlation between the degree of digital parts and instruments imports and the degree of total digital exports (correlation of 0.994 for digital parts and 0.918 for digital instruments). The correlation between DPTs imports and total digital exports is much smaller (0.471).

This shows that countries that import a larger amount of digital parts and digital instruments also tend to the countries that export more digital products. This suggests that these countries are involved in a digital value chain, whereby they import the digital parts and instruments, process and assemble them, and export finished machinery (or in the case of Thailand, digital parts – likely more processed ones).

Figure 59. Correlation (using 63 LMICs for which exports and imports data are available)



Correlation: 0.471978



Correlation: 0.994123

Correlation: 0.91895

Digital value chains

Building on this insight, we analyse the regional integration of 'digital value chains', that is, the extent to which digital products trade takes place with countries from the same region.[16]

We present the regional integration for total imports in four major regions: East and Southeast Asia, Americas, Africa and Europe. Europe shows the highest regional integration – with intra-regional trade accounting for 66.2 per cent of its total trade. East and Southeast Asia rank second with 48.2 per cent intra-regional trade, followed by The Americas (37.1 per cent) and Africa fourth (16.9 per cent).

Table 13. Regional integration - Total imports

	Importing region				
Origin of imports	East and Southeast Asia	Americas	Africa	Europe	Other
East and South-East Asia	48.2%	33.8%	23.8%	14.6%	36.2%
Americas	13.4%	37.1%	8.4%	8.3%	11.9%
Africa	2.6%	1.4%	16.9%	2.8%	4.5%
Europe	14.9%	20.2%	34.0%	66.2%	24.0%
Other	20.9%	7.5%	16.8%	8.1%	23.4%

Source: Authors

When we look at trade in digital products, the picture differs significantly. The region that stands out as the most integrated is East and Southeast Asia, with 70 per cent of its trade occurring within the region. Europe ranks second, but with a considerably lower score than for total imports (43.2 per

[16] See EQuIP Tool 4 on global value chains that discusses different types of trade data for different types of value chain-related analyses.

cent), and The Americas and Africa showing even lower percentages (17.7 per cent and 2.5 per cent, respectively).

Table 14. Regional integration – Digital imports (using 156 selected digital products)

Origin of imports	**Importing region**				
	East and Southeast Asia	Americas	Africa	Europe	Other
East and South-East Asia	70.0%	68.6%	31.6%	45.0%	71.2%
Americas	6.9%	17.7%	3.5%	7.5%	9.5%
Africa	0.0%	0.0%	2.5%	0.3%	0.1%
Europe	5.6%	8.8%	15.7%	43.2%	11.5%
Other	17.5%	4.9%	46.8%	4.0%	7.7%

Source: Authors

The results demonstrate that the East and Southeast Asia region is highly integrated in digital trade, but they also highlight that these countries are the leading global sellers of digital products. This is evident in the high percentage of digital products other world regions import from East and Southeast Asian countries. The Americas, for example, import 68.6 per cent of their digital products from East and Southeast Asian countries.

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Annex

A1 Digital technology classification and data sources

Technology classifications are widely used in industrial development and technological change analyses, as well as in the development of more granular indicators of industrial competitiveness and benchmarking tools. Technology classifications allow for the clustering and, in some cases, ranking of different industrial sectors or products—both goods and services—based on their level of technological sophistication or other distinctive features. One well-known and widely used technology classification is Lall's taxonomy, which is also used by UNIDO. Building on the Organization's work on industrial competitiveness and that of the OECD (1994) on technology intensity-based taxonomies, Lall (2001) developed a taxonomy that distinguishes groups of products characterized by different degrees of technological sophistication and generated in different sectors of the economy. These are resource-based, low-technology, medium-technology and high-technology manufactured products.

Box 12. Technology classification of export by Lall – ISIC and SITC Rev. 3

Technology classification of exports according to SITC Rev. 3	
Type of export	SITC sections
Resource based exports	016, 017, 023, 024, 035, 037, 046, 047, 048, 056, 058, 059, 061, 062, 073, 098, 111, 112, 122, 232, 247, 248, 251, 264, 265, 281, 282, 283, 284, 285, 286, 287, 288, 289, 322, 334, 335, 342, 344, 345, 411, 421, 422, 431, 511, 514, 515, 516, 522, 523, 524, 531, 532, 551, 592, 621, 625, 629, 633, 634, 635, 641, 661, 662, 663, 664, 667,689
Low-technology exports	611, 612, 613, 642, 651, 652, 654, 655, 656, 657, 658, 659, 665, 666, 673, 674, 675, 676, 677, 679, 691, 692, 693, 694, 695, 696, 697, 699, 821, 831, 841, 842, 843, 844, 845, 846, 848, 851, 893, 894, 895, 897, 898, 899
Medium-technology exports	266, 267, 512, 513, 533, 553, 554, 562, 571, 572, 573, 574, 575, 579, 581, 582, 583, 591, 593, 597, 598, 653, 671, 672, 678, 711, 712,713,714, 721, 722, 723, 724, 725, 726, 727, 728, 731, 733, 735, 737, 741, 742, 743, 744, 745, 746, 747, 748, 749, 761, 762, 763, 772, 773, 775, 778, 781, 782, 783, 784, 785, 786, 791, 793, 811, 812, 813, 872, 873, 882, 884, 885
High-technology exports	525, 541, 542, 716, 718, 751, 752, 759, 764, 771, 774, 776, 792, 871, 874, 881, 891

Technology classification of manufacturing value added according to ISIC Rev. 3	
Type of activity	ISIC division, major groups or groups
Resource based manufacturing	15, 16, 17, 18, 19, 20, 21, 22, 36, 37
Low-technology manufacturing	23, 25, 26, 27, 28, 351
Medium- and high-technology manufacturing	24, 29, 30, 31, 32, 33, 34, 35 (excl. 351)

Source: Authors

To construct the digital capabilities indicators presented in Section 0 and hence assess the extent to which countries learn to digitalize and gain industrial competitiveness, we present a new *Digital Technology Classification* here. The classification identifies tradable products that are classifiable as digital production technologies, parts and instrumentation. As mentioned above, the main data source for digital indicators is UNCOMTRADE data. A detailed explanation of the methodology used to construct such a classification follows, since it involves several original methodological steps.

- **Step 1: Data selection and levels of product classification**
  We start by extracting trade data at the six-digit level to be able to distinguish production technologies that present a potential for digitalization (PTDP) from advanced digital production technologies (ADPT). While there are some caveats in using trade data[17], they represent a very rich data source, with granular data available for most countries.

- **Step 2: Selection of the most suitable product classification**
  Since we are dealing with very recent technological developments, we use the most recent product classification available: the Harmonized System (HS) 2017. The advantage is that it includes some new product codes that classify products based on their digital content (e.g. differentiating between machines that connect to the internet and those that do not).

- **Step 3: Identification of PTDP among tradable products**
  To focus our analysis on industrial machinery, parts and instrumentation, we restrict our analysis to a subgroup of the entire HS 2017 classification with the following classes:

[17] These include: 1. Not accounting for the fact that some countries might produce many of the products domestically, and thus do not appear in trade data; 2. Not being able to capture which activities were carried out in the country, and thus how much value was actually added in the country itself; 3. Not differentiating trade carried out by multinational corporations (MNCs) or local firms.

- HS 2017 Chapter 84: Nuclear reactors, boilers, machinery, and mechanical appliances; parts thereof;
- HS 2017 Chapter 85: Electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles;
- HS 2017 Chapter 90: Optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and apparatus; parts and accessories thereof.

In addition, with a view to excluding machinery and appliances for consumer use—considering that our focus is on digital manufacturing production—we intersected these three chapters with selected chapters of the Broad Economic Categories 4 (BEC 4) classification:

- BEC 4 Chapter 41: Capital goods (except transport equipment);
- BEC 4 Chapter 42: Parts and accessories;
- BEC 4 Chapter 22: Industrial supplies not elsewhere specified, processed.[18]

By applying these criteria, we identify a sub-group of 818 products.

- **Step 4: Identification of the ADPT**
  From the extensive list of products with digital potential, we identify those that are directly identifiable as digital production technologies. Specifically, from the sub-group of 818 products (HS 2017 Chapters 84, 85 and 90 intersected with BEC 4 Chapters 41, 42 and 22), we select a set of keywords and check their presence in the 'self-explanatory description' of each 6-digit product code. Several keywords were automatically tested and their results evaluated. The keywords selected were:
    - (E)lectronic,
    - (D)ata,
    - (N)umerical,
    - (N)etwork,
    - (A)utomatic,
    - (T)ransistor,
    - (S)emiconductor,
    - (I)nstruments,
    - (A)pparatus,
    - (W)afers,
    - (C)alcul-,

[18] We also looked at BEC 21 'Industrial supplies not elsewhere specified, primary', but decided to not include it as the only class that emerged after the intersection was class 854810 '*Waste and scrap of primary cells, primary batteries and electric accumulators; spent primary cells, spent primary batteries and spent electric accumulators*', which does not match with our focus on digital production technologies.

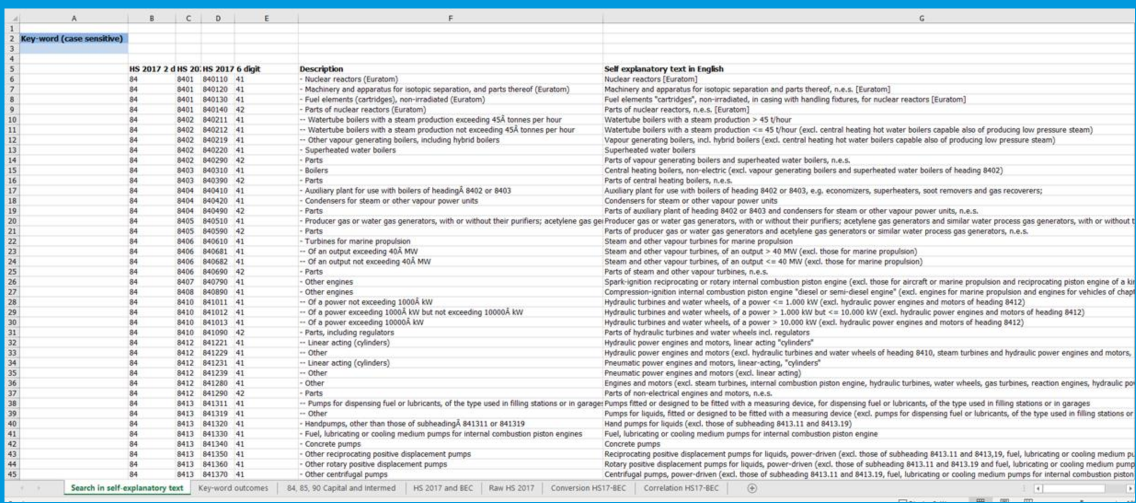
- (C)ontrol,
- (T)esting,
- (M)eter,
- (W)eight.[19]

After having applied these filters, the number of products dropped to 264. We then conducted a manual check and excluded products that clearly do not have any relation to digitalization.[20] This further reduced the list to 156 products that are highly related to digitalization with a high degree of confidence. These 156 products were coded into the Digital Technology Classification and used to build the indicators.

Box 13. Digital Technology Classification and Excel tool

The *Digital Technology Classification* consists of a list of 156 products defined at the 6-digit product level and whose 'self-explanatory description' makes a direct and explicit reference to digital production technologies, parts and instrumentations. Products from this classification are extracted from three HS 2017 chapters 84, 85 and 90 and intersected with BEC 4 Chapters 41, 42 and 22.

The following Excel tool provides search, identification and clustering functions.



Source: Authors

[19] Other keywords were tried as well but excluded, as their results were either void, redundant or misleading. These included: wireless, artificial, computer, automated, sensors, printer, digital, chips, conductor, additive, internet.

[20] Some products included the key words but not with the intended meaning. For example, many products had the word 'numerical' in the description 'not numerically controlled', thus exactly the opposite of what we were trying to capture. Another example: Product code 844711 'Circular knitting machines, with cylinder diameter <= 165 mm' includes the word 'meter' within 'diameter' which is completely unrelated to what we sought to capture with the keyword 'meter', which was aimed at thermometers, electrical current meters and other sensors. Also, all medical devices were excluded from the analysis.

- **Step 5: Identification of digital services**
  The digital service indicators were calculated using UNCOMTRADE data with the Extended Balance of Payment Services Classification 2002 (EBOPS, 2002). We used the EBOPS 2002 Chapter 7 – "Computer and information services" as our identification strategy for digitalization-related services. Ideally, only sub-chapter 7.1 "Computer services" and sub-chapter 7.2.2 "Other information provision services" should be used. However, data are very scarce at this level of disaggregation, so we prefer to use the higher level of aggregation as a proxy, as data at that level are much more readily available.[21]

[21] The downside of using the Chapter 7 is that it also includes sub-chapter 7.2.1 "News agency services", which is not related to digitalization. However, it is an adequate proxy, and data are available for many more countries at this level.

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