UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Inclusive and Sustainable Industrial Development Working Paper Series

WP 16 | 2019

A COMPARATIVE ANALYSIS ON DIGITALIZATION IN MANUFACTURING INDUSTRIES IN SELECTED DEVELOPING COUNTRIES: FIRM-LEVEL DATA ON INDUSTRY 4.0

DEPARTMENT OF POLICY, RESEARCH AND STATISTICS

WORKING PAPER 16/2019

A comparative analysis on digitalization in manufacturing industries in selected developing countries: Firm-level data on Industry 4.0

David Kupfer
Institute of Economics, Federal University of Rio de Janeiro

João Carlos Ferraz
Institute of Economics, Federal University of Rio de Janeiro

Julia Torracca
Institute of Economics, Federal University of Rio de Janeiro

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Vienna, 2019

Acknowledgments

The authors thank Alejandro Lavopa, UNIDO staff and the participants of the 2nd Expert Group Meeting to IDR 2020 for their comments and suggestions.

This is a Background Paper for the UNIDO Industrial Development Report 2020: Industrializing in the Digital Age.

Table of Contents

List of Figures

List of Tables

Abstract

This empirical study investigates the current adoption patterns and future perspectives of digitalization in industrial firms in developing countries, with a view to understanding how diversity and heterogeneity can determine the adoption of digital technologies at firm level. To achieve this goal, a comparative analysis is conducted based on surveys of 1,158 firms of varied sizes and manufacturing industries carried out between 2017 and 2019 in Brazil, Argentina, Ghana, Thailand and Viet Nam. The surveys asked firms about their current and expected use of digital technologies over the next five to ten years; the efforts currently being undertaken to enable future use of such technologies, as well as the foreseeable impacts of digitalization on skills, energy consumption and sustainability. The main results show that very basic generations of digital technologies currently prevail in the surveyed countries, but expectations for the future are that major strides towards digitalization will be made. Nevertheless, the majority of firms is not well prepared to achieve the projected future advances, with large firms in high- and medium high-technology industries seeming better positioned to introduce digital technologies compared to their smaller peers from lower-technology industries.

Keywords: Industry 4.0; digitalization; manufacturing industries; industrial firms; developing countries.

1. Introduction

The objective of this paper is to conduct a comparative analysis of digitalization in industrial firms in five countries: Argentina, Brazil, Ghana, Thailand and Viet Nam. The analysis is strongly empirically oriented as it is based on surveys of firms carried out between 2017 and 2019. All surveys included key questions and took an innovative approach to questioning firms about their current and expected adoption level of digital technologies (DTs). The surveys differed in certain aspects: the surveys in Argentina, Ghana, Thailand and Viet Nam explored issues associated with skills and employment; the surveys in the latter three countries also question firms about the implications of digitalization on energy efficiency and environmental sustainability.

Building on the understanding that digitalization is a process of convergence of established and emerging technologies, this paper examines the extent to which different DT generations can coexist within firms. It explores the development from a stand-alone use of established technologies in specific business functions—such as product development—towards an integrated, interconnected and intelligent economic system, bringing together internal business functions and external relations of a firm in real-time with its clients and suppliers.

This paper examines which DT generation is currently being used by firms in Argentina, Brazil, Ghana, Thailand and Viet Nam and their expectations in digital developments over the next five to ten years, comparing adoption patterns among the countries, firm size, industry and current engagement efforts to prepare for the projected future. Given the novelty of the surveys' approach, specific indicators were developed to allow for a sound comparative exercise. Finally, the sub-group of firms that are more advanced in the adoption of DTs was questioned about the implications of these technologies on skills, employment, energy efficiency and environmental sustainability.

The five-country surveys, covering approximately 1,200 firms, provided the empirical base to examine the extent to which advancements in digitalization are evolving in each country. Furthermore, we placed a focus on whether two structural features of developing countries, namely diversity—the co-existence of different patterns of specialization in countries' production structure—and heterogeneity—the co-existence of different levels of capabilities and competences among firms, industrial sectors—is also present in the digitalization adoption patterns.

The structure of the paper is as follows. Section 2 presents the analytical and methodological framework underlying this exercise, including a review on the debate on digitalization. Section 3 provides a detailed account of the research process in the five countries: content of the questionnaire (including common and distinctive features); how surveys were carried out and the method used in the design and development of a comparable database for the five countries. A comparative analysis is carried out in Section 4 and covers two topics. The first is the discussion and comparison of the current and expected adoption of DTs, as well as the nature of measures currently being undertaken by the surveyed firms to achieve their projected DT generation. The second topic is the discussion of the implications of the current and projected adoption of advanced DTs on employment and skills, energy use and sustainability. The final section summarizes the main results and presents the main lessons gleaned from the comparative analysis.

2. Analytical and methodological framework

2.1. Goals and motivations

The main goal of this study is to understand the current adoption patterns and future perspectives of digitalization in industrial firms in selected developing countries. The central research question driving this study is how structural and behavioural features of firms can determine the adoption of DTs. The proposed analytical framework rests on the concepts of diversity and heterogeneity. Diversity relates to the co-existence of many different patterns of specialization in the production structure of countries and regions. Heterogeneity refers to the co-existence of many levels of capabilities and competences in the production structure of either a country, a region, a sector or firm, or across different firms, industries or regions, for example. Although diversity is a common feature of every industrial formation in the world, heterogeneity usually constitutes a key distinctive feature of industrial sectors and firms in developing countries. This study therefore examines the extent to which different DT generations coexist among firms with similar structural features such as location (country), size and industry.

The following section discusses the nature of DTs and its development over time. The discussion addresses the key elements for constructing the analytical framework and the empirical strategy adopted in the five national surveys carried out for the present study.

2.2. Digital technologies: implications for business models and competitiveness

In a broad sense, digitalization refers to advances in information and communication technologies (ICTs) which changes the way firms produce and market their products, as well as how people work and how they buy and consume these goods. Digitalization is usually associated with "Industry 4.0", a concept first introduced in Germany nearly a decade ago. The very concept of Industry 4.0 involves the notion of evolution towards advanced digital generations. It also encompasses a varied group of digital solutions, applied to different business functions of firms – product development, production, relations with suppliers and clients, etc. The most advanced stage allows for the integration of business into digital networks and the fusion between real and virtual environments, with significant impacts on how industrial firms create and deliver value to customers. Also, the “Industry 4.0” concept blends “soft” technologies (big data, artificial intelligence) with “hard” ones (sensors, robots, high performance computers) by means of communication networks that allow relevant information to be made available in real-time along a supply chain. It is increasingly becoming clear that 4.0 technologies may result in disruptive changes in business models, competition patterns and market structures.

It must also be considered that the path towards Industry 4.0 has been made possible due to a significant decrease in the costs of core technologies, such as those related to sensors, processing and storage of large databases. Thus, the supply and use of DTs are expanding exponentially due to steadily decreasing costs (IEL/NC et al., 2018). Nonetheless, the 4.0 digitalization of an industrial firm requires substantial investments. Hence, although a trend towards digitalization is clear, the pace of diffusion differs significantly across industrial sectors and countries, with developing economies still at an early stage.

The essence of Industry 4.0 is the merging and integration of different but complementary DTs into converging systems. Rosenberg’s seminal concept of technological convergence (1963), the notion of generic technologies (Gambardella & Torrisi, 1998) and of general purpose technologies (Cantner & Vannuccini, 2012) are therefore quite useful.

According to Andreoni (2017), five features distinguish key technological systems such as digital ones: they are transversal, for they can be used in and have an impact on various industries and supply chains; they are embedded into integrated systems; they potentially enhance quality, allowing for a continuous improvement of products and services; they are likely to enhance productivity by allowing for continuous improvement of production processes and operations; and they are strategic, in the sense that they will play a major role in addressing future social and economic challenges. Digitalization in manufacturing should be understood as an evolutionary process (Kagermann, Wahlster & Helbig, 2013). Firstly, it involves specificity because it is a context-based process and because solutions are idiosyncratic to firms, value chains, locations and markets. Secondly, adopting DTs yields long-term benefits due to cumulative learning and experimentation with technologies, systems and processes.

An OECD report (2017) points out that Industry 4.0 firms are firms that have been able to effectively catch-up with and create specific solutions based on innovations on three fronts: production (“advanced manufacturing”), information processing (big data, cloud computing, etc.), and integrative use of information (artificial intelligence, smart systems, etc.). In light of the competitive pressures and environmental stimuli firms are subject to, many different solutions from the vast range of technologies can be combined to solve the specific problems the manufacturing sector faces.

Nonetheless, neither are all technologies associated with digitalization from the fourth generation, nor will all firms indiscriminately adopt them. Some DTs have been used in manufacturing for a very long time, such as microelectronic-based automation, robotization, mobile communication, sensors and CLPs. Nonetheless, new digital generations will evolve along the trajectory of integration, interconnection and intelligence. Firms' decision-making process to engage in DTs is quite complex. Starting from the assumption that industrial firms are somewhat familiar with DTs, an investment decision must take into account the purpose, the business function or the scope of the business functions and, building on that, the choice of DT generation. More importantly, investments in soft and hard technology solutions should consider the availability and mobilization of further resources, their existing and, more importantly, emerging capabilities, as advanced digital-biased skills are a novelty and most firms have scarce resources.

DTs represent a firm's qualitative competence and a competitive leap for firms. Going digital can radically alter performance patterns and modes of managing and monitoring operations. If successfully introduced, DTs lead to increased efficiency, lower transaction costs and optimization of logistics. For example, information and communication technologies combined with artificial intelligence result in real-time approximation (represented by information flows) of activities carried out by employees, suppliers, service providers or customers in different organizational, business units or industrial plants.

The digital-led integration of business functions may have resulted in changes to a firm's organizational structure and relations with customers and suppliers, potentially leading to lower administrative costs and stocks of parts, components and finished products. DTs also imply greater flexibility in the design, production and delivery of solutions to meet clients' demands. Additionally, the use of digital solutions such as artificial intelligence and augmented reality virtually simulate production and market environments, allowing for the development and testing of new products and services in a much more cost effective way, thus reducing time to market, from R&D to sales

In a nutshell, DTs potentially allow firms to alter their business models towards greater efficiency, product customization, shorter lead times and increased flexibility, especially as regards the use of resources (whether tangible or intangible). Thus, business models and value chains may evolve towards higher levels of integration, interconnection and intelligence, thus potentially enhancing the competitiveness and market position of industrial firms.

2.3. Digital technologies: implications on skills and employment

The implications of digitalization on skills are a much debated topic, given the complex nature of the changes involved: the appropriate skills profile and the adequate ratio of employees to the tasks that are relatively unknown if the reference is the highest potential integration, interconnection and intelligence DT might bring about. As mentioned in the previous section, this is the "ultimate reference point" for business models. The wide variance in adoption formulas available to firms in terms of digital generation and the scope of business functions that can be digitalized has also gained attention. The organizational, capabilities, skill and employment implications have a direct relationship with the nature of digital investments that need to be made by an industrial firm at a given moment.

Thus, it comes as no surprise that uncertainty still prevails as to how advanced DTs will affect skills and employment patterns in the short and medium term. Economic history shows that in times of profound technological change, some countries and firms manage to absorb innovations while others do not and start lagging behind. Thus, the impact of DTs on work and skills is likely to differ across space and agents. Nonetheless, the future of work and skills in the face of rapid digitalization should be discussed. A brief non-exhaustive discussion on specific issues related to skills and jobs is provided here based on the account in Albrieu et al. (2019a).

The following patterns observed in previous eras of technology-intensive structural changes, just like the current one associated with DTs, may induce transformations in the skill profile and quantity of jobs needed to perform production activities. Experts now argue that "technological unemployment" will soon appear. Most importantly, as DTs may reduce the marginal costs to replicate goods to a minimum, traditional production structures associated with standardized mass production are largely at risk, especially those based on the extensive use of labour in routine tasks. There is also concern about the impacts of automation on the types of tasks performed within jobs. Evidence shows that workers will dedicate more hours to complex tasks and interpersonal relations rather than to less complex tasks, which will have become automated (Pounder and Liu, 2018). It is therefore reasonable to explore the extent to which digital automation might actually result in job loss.

Technological change usually affects skills demand and tends to favour workers with skills that complement the new technology, according to Acemoglu (2002). However, the set of skills that are necessary to perform work in a workplace that has introduced fourth generation DTs has yet to be defined, although it is expected to be concentrated in three groups: 1) general cognitive knowledge, 2) specific technology-related knowledge (or IT skills), and 3) socio-emotional (or soft) skills.

A report prepared by Deloitte (2017) predicts that soft skill-intensive occupations will account for two-thirds of all jobs by 2030 as compared to half of all jobs in 2000, and that the number of jobs in those occupations is likely to increase 2.5 times more than the employment rate in other occupations. As a result, the future of labour will essentially depend on human brain power supplementing the flexibility derived from the ability to process and integrate information of many different kinds, as well as to perform complex tasks and to communicate them to others. From this perspective, opportunities will arise in activities that capitalize on strictly human capacities, such as curiosity, imagination, creativity and social and emotional intelligence. Hence, over 30 per cent of all new high paying jobs will be linked to "essentially human" social attributes (Levy and Murnane, 2013). The increasing diversity of the workforce is likely to intensify demand for more creative labour, particularly in emerging "hybrid" jobs that integrate technical and project management skills, mobilizing competencies associated with various domains of knowledge.

While the need for technical skills remains high, the need for people with communication, interpretation and synthetic thinking skills is on the rise. These new social skills, in turn, are leading to a change from an education model focussed on STEM (science, technology, engineering and math) to one focussed on STEAM, which includes general culture and arts education (indicated by the letter A in the acronym). The skills required to meet the challenges posed by the advent of DTs call for a restructuring and modernization of school curricula, especially in the fields of logic, creative thinking, problem solving, project work and teamwork. Changes in education in all fields and at all levels, including formal and non-formal learning mechanisms, are necessary. Such profound change implies the need for novel education models. The need to replace traditional "cocoons" of scientific disciplines that characterize most of today's education is an immense challenge for all societies (IEL/NC et al., 2018). Another relevant issue is the impact of digital innovations on "professionalization". In an industrial society, the notion of a 'career' plays a central role in defining a stable and steady set of capabilities a professional must possess to perform a given "job" or have a given "occupation" to resolve problems in accordance with the organization's or industry's needs. Within the emerging scenario of digital transformation, not only is the set of capabilities underlying a number of "occupations" rapidly changing, but it continues to remain undefined; stable jobs and professions associated with formal qualifications that once outlined the traditional "professional career" are being replaced by more flexible and fluid employment relationships. From the perspective of the individual, success in the workplace is now being treated more as a result of the individual's own efforts and self-efficacy to cultivate an autonomous mind set and to continuously acquire high-value skills to meet the constantly changing training requirements.

To conclude, digital innovations associated with Industry 4.0 technologies have not only changed the relationship between people and computers—whether in the realm of production, consumption or work—but have also given rise to increasingly integrated, interconnected and intelligent systems in which individuals play a crucial role. As DTs are disseminated and the set of skills and capabilities required of workers begin to be adjusted, people and machines will increasingly complement each other, with the former becoming more relevant and less substitutable, since it is human input that defines how machines will perform and how they will enhance and maintain human capabilities.

2.4. Digital technologies: implications for developing countries

In developing countries, where heterogeneity is a key feature of their production structure, it may be assumed that with respect to DTs, adoption patterns will vary depending on the firms' profile. That is, within the same time and space framework, firms producing goods and services using traditional production processes and structures may co-exist with firms in which digitalization represents an essential part of their business strategy and means of production.

The study of DT adoption patterns in Argentina, Brazil, Ghana, Thailand and Viet Nam provides valuable insights into digitalization in developing countries, as they all share two common features: 1) diversity, and 2) heterogeneity. Country-specific features, however, preclude making any generalizations when drawing lessons from the experiences of these countries. For example, they all have a different structural configuration in terms of the geographic location of firms, the role of industrial firms in global value chains, and the relative importance of different industries in the country's industrial matrix, among others.

Nevertheless, digitalization is an emerging process that has yet to be consolidated. This means that robust firms and governments in developing countries will also undertake efforts to achieve digitalization. The concepts initially proposed by Abramovitz (1986) can be adapted to shift the discussion to the firm level and investigate how firms incorporate digital technologies. In developing countries, the focus must essentially be on firms that are at a more advanced DT stage (classified as firms that are forging ahead); firms that are lagging behind and firms that have the capability of moving forward with DTs (classified as firms that are moving on) (Ferraz et al., 2019).

In light of this, the relevant issues and corresponding implications for public policy that must be addressed are as follows: should the adoption of advanced DTs deliver competitive advantages, would firms that are forging ahead force out those that are lagging behind? In other words, if the access to and adoption of DTs became pervasive, would firms that are lagging behind be able to catch up and would windows of opportunity open up for "latecomers"? Who would benefit from technological change and sustainable growth in the long term? These are the questions the present comparative analysis seeks to answer.

2.5. Detecting digital technologies at firm level: the traditional approach

A vast body of literature exists on the definition of DTs, their potential uses and implications on various factors, particularly business, skills and employment. Much effort has been undertaken to gather, compile and disseminate information on the emergence and diffusion of these technologies at the country level – notably, at the developed country level. This notwithstanding, comparable survey-based country and firm-level data are scarce. Additional studies are necessary to comprehensively examine the implications of digitalization for corporate planning and policy assessments, especially in developing countries.

Developing countries must determine which DTs firms have already adopted and which ones they expect to adopt in the near future. Additionally, the profiles of digitally advanced firms and digital laggards must be defined, as well as the implications on skills and labour and major challenges, risks and opportunities associated with digitalization.

As reviewed in IEL/NC et al. (2018) and Ferraz et al. (2019), several surveys conducted by international consulting firms, such as Accenture (2017), Deloitte (2018, 2017), McKinsey Global Institute (2018) and Geissbauer, Vedso and Schrauf (2016) assessed the level of diffusion and the impacts of Industry 4.0-related digital technologies. Many of them focus on the assessment of specific technological solutions and measure the impact of diffusion in terms of potential benefits. Attempts are often made to determine enterprise readiness to incorporate DT into different organizational procedures.

Although these studies provide supporting evidence that is quite useful for understanding the emerging process of technological change related to the Industry 4.0 paradigm, their overall approach has several shortcomings. According to Albrieu et al. (2019a), they are related to the vast number of possible technological solutions; their specificity according to each industrial activity and the specific processes or business functions and similar such factors within each activity. More importantly, digital solutions have been around for a long time, i.e. only focussing on the most advanced solutions disregards the fact that some of the previous generations of technologies are not necessarily obsolete from a practical perspective.

Due to these shortcomings, a recent study carried out in Brazil to investigate the DT adoption patterns by industrial firms (IEL/NC et al., 2018) developed an alternative approach. This approach differs from the traditional one in three relevant aspects. Firstly, departing from the specification of an industrial firm as a set of business functions, the alternative approach focusses on the role different DT generations have played in each firm and not the adoption (or not) of specific technologies by the firms. Secondly, as technological progress is rapidly changing as is firms' intention to adopt DTs, the current use and future trends of DTs are determined. Thirdly, to "ground" future expectations, firms were asked about the current measures they are taking to prepare for their projected future by plotting a dynamic trajectory instead of a static point in time.

2.6. Detecting digital technologies at firm level: an alternative experimental approach

The development of the experimental empirical research strategy builds on three assumptions. Firstly, as DTs have been available to and used by industrial firms across different industrial sectors for at least three decades, it must be assumed that firms are using DTs from different generations, not only fourth generation DTs. Secondly, DTs are used in specific "locations" of a firm—hereinafter referred to as business functions—such as supporting product design, production management or relations with suppliers. Thirdly, as firms may be using DTs regardless of what industry they operate in, the questions should be addressed to all firms, regardless of the economic activity they perform.

The concept of "digital technology generation" is key for this alternative research approach: it requires a time-related dynamic approach, since it seeks to capture the evolutionary logic behind the technological progress observed in DTs. When properly specified, these DT generations can be subject to observations in business environments and, if successful, elucidate the extent to which diversity and heterogeneity features of developing countries are present in the digital domain.

The analytical framework defines technological generations as different "levels" or "stages" of technological development in terms of the nature of firms' DT use to perform a given number of business functions. Taking the Industry 4.0 paradigm as the fundamental reference point, four generations of DTs were stylized, from the most rigid type (first generation) to the most integrated, interconnected and intelligent one (fourth generation), as detailed below:

- **First generation - rigid production**: the use of DTs for a specific purpose within a specific function (e.g. CAD in product development).
- **Second generation - lean production**: the use of DTs that partially link two or more business functions (e.g. CAD-CAM, linking up product development and production processes).
- **Third generation - integrated production**: DTs are integrated and interconnected in all business functions (e.g. enterprise resource planning software applications or web-based sales support systems).
- **Fourth generation - integrated, connected and smart production**: use of DTs with information feedback within the organization to support decision-making processes (e.g. business management with support from big data and artificial intelligence).

As it is assumed that firms' strategies, competencies and performance differ from one another, it is also reasonable to assume that they differ with regard to how and for what purposes DTs are used. To better capture the "location" of the introduction of digital solutions, five business functions are specified: 1) relations with suppliers, 2) product development, 3) production management, 4) customer relationships, and 5) overall business management.

In line with the research carried out by IEL/NC et al. (2018), presented in Table 1, the concepts of technology generations and business functions were combined to create a roadmap of four digital technology generations, each corresponding to different ways the performance of five business functions can be carried out.[1]

[1] Similarities between the 4h generation of the proposed framework and the German framework Industrie 4.0 are purely coincidental.

Table 1: Digital technology generations according to business functions

Generation	Supplier relationship	Product development	Production management	Client relationship	Business management
G1	Manual transmission of orders (e.g. fax)	Stand-alone computer aided design - CAD	Stand-alone automation	Spread sheet registry of contacts	Information systems by area/department
G2	Electronic transmission of orders (e.g. email)	CAD - CAM	Partially or fully integrated CAM	Automated devices to support sales	Enterprise resource management in few areas
G3	Digital system for processing orders, stocks & payments	Integrated data product system	Process execution, automated system	Internet-based support for sales & after services	Integrated platform to support decision-making
G4	Real-time web-based relations	Virtual modelling	Machine to machine - M2M system	Client relationships based on online monitoring, product use	Business management supported by big data analytics

Note: DT generations were specified with the support of specialized engineers. The best foreseeable technologies in 2017 were considered to consist of G4.

Source: I2027 Final Report (IEL/CNI et al., 2018).

Technologies included in G1 and G2 generations have been around and available for as long as numerical control programming systems exist (late 1950s), although solutions such as CAD have evolved and been widely disseminated in recent years owing to parametric engines. G1 is best described as a stand-alone process, as firms use DT for very specific tasks in localized business functions. Their relations with suppliers and clients are based on manual or telephone transmissions and registrations are carried out via ledgers, logbooks and/or spreadsheets. By adopting these technology generations, even if firms' efficiency and the quality of their products, processes and operations are significantly improved, the transition from G1 to G2 does not require major efforts in terms of organizational changes and investments. The development and associated changes involved in the transition from G1 to G2 are incremental, and firms may end up being lean, quality-bound and productive.

At G3, all business functions are digitally integrated. If the ERP systems function effectively, the flow of information allows for the conversion of various business functions. At this stage, the standardization of production, communication and administrative procedures must be well developed. As a result, downtimes and production waste due to information failures are minimized. At the same time, the degree of involvement with suitable partners—suppliers and clients—is high and the firm can activate or respond to demands near real-time. Transitioning from G2 to G3 requires significant efforts: firms should make the necessary investments to fully integrate their business functions and to comprehensively and effectively standardize their processes and information systems.

The G4 digitalization level is very high: the enterprise is a cyber system. If effectively and comprehensively implemented, the best representation of a G4 enterprise is that it has a digital twin: process management and product development are based on virtual modelling; big data and artificial intelligence are fully being used, including in external relations and basic process prevention, and optimization in decision-making can in fact be delegated to the existing cyber system. To move from G3 to G4, substantial changes are necessary, as G4 is characterized by the use of advanced communication devices, robotization, sensorization, big data and artificial intelligence, among others. At this stage, G4 solutions are most likely introduced gradually, but the end result is an integrated, interconnected and "intelligent" business model, that differs considerably from the one adopted by a full G3 firm.

Aside from determining firms' current DT use (or the technological generation in use), the investigation also aimed to denote the firms' future expectations in terms of digital technology adoption. Consequently, firms were asked about the DTs they expected they would be using in five to ten years. To better understand firms' intention to evolve from their current technological stage to the projected one, the nature of the efforts they are currently undertaking (if any) to achieve the projected level of digitalization had to be assessed.

Firms were therefore asked to identify which types of measures were being undertaken with the purpose of achieving the projected level of digitalization for each business function: no action at all, ongoing initial studies, planning has already started or has been formalized, and formal plans have been formalized and are already in place. It is assumed that qualitative leaps towards a higher technology generation can only be achieved by means of explicit entrepreneurial efforts involving business planning and investments to acquire technologies and adequate resources in terms of physical infrastructure, knowledge and skills. This approach not only reveals firms' actual and expected digital technology generation—a preliminary sign of development and progress—but this foresight exercise also ascertains firms' current level of readiness to prepare for the future.

3. Field research strategy and implementation

Experts agree that the availability of empirical data specifically on industrial firms' digitalization patterns enhances the understanding of the nature and pace of such phenomena. In order to provide entrepreneurs and policymakers with quality information on the nature of digital transformation, data was collected from 1,158 firms from five developing countries with support from different partners[2].

The data represents the current and projected adoption of DTs by industrial firms. The study mapped the digital technology generation firms see themselves as having employed to date and the DTs they expect to be using in the next five to ten-year period, taking into account the empirical roadmap presented in the previous section. In addition, the study also collected information on the potential impacts of advanced digitalization on employment and skills, as well as on energy consumption and sustainability.

This comparative exercise is based on data collected from five different and independent surveys. The first one was carried out in Brazil in 2017 as part of the I2027 initiative (IEL/NC et al., 2018); the second one was conducted in Argentina in 2018 (Albrieu et al., 2019a); the remaining surveys were carried out in 2019 in three developing countries selected by UNIDO (Ghana, Thailand and Viet Nam).

This chapter describes the main features of each survey, the specifications of the sampling method adopted in each case and the samples obtained. It also elaborates on the general procedures of data collection and screening used in each national survey. Finally, the procedures used to design a comparable database for the five countries are explained. Sectoral commonalties are the guiding feature of the establishment of the comparable database.

3.1. Questionnaire design and procedures for data collection

Each survey addresses specific issues, but all three surveys share common features. The most complete questionnaires were applied in Ghana, Thailand and Viet Nam, where surveys contained three blocks of questions (in addition to questions related to the main features of firms): (i) current and expected DT use; (ii) employment and skills, and (iii) energy and sustainability. The Argentine survey did not explore the latter two sets of questions, while the Brazilian one focussed on current and expected use of DTs only.

[2] UNIDO in Ghana, Thailand and Viet Nam, Albrieu et al 2019[a]) in Argentina and IEL/CNI (2018) in Brazil.

The following examples of questions illustrate the nature and scope of each survey:

- Current and expected use of DTs: “To manage supplier relationships, which of the following technologies are currently being used and are expected to be adopted in the upcoming years (five to ten years)? (1) Manual electronic purchase order transmission; (2) Electronic purchase order transmission; (3) Electronic handling of inventories, purchases and invoices; (4) Real-time supply chain management.”
- Readiness levels: “Which course of action is the firm currently taking towards the adoption of the technology(ies) to be adopted in the next five to ten years? (1) No action nor studies; (2) Initial studies, but no action yet; (3) Approved project but no clear plans for implementation; (4) Actions already in progress/execution.”
- Skills: “In the next five to ten years, how important will these skills be when hiring a new employee (very important = 5, somehow important = 4, not that important = 3, not important at all =2, do not know = 1): Soft skills (team work, communication skills...), Skills related to human-machine interaction (design, use of new technologies); Skills related to science, technology, engineering and mathematics (STEM); Skills required for manual and repetitive tasks.”
- Energy and sustainability: “In the next five to ten years, how important (very high contribution = 1, high contribution = 2, moderate contribution = 3, low or no contribution = 4) will the contribution of advanced digital and production technologies in improving environmental sustainability be in any of the following dimensions: saving water; saving energy; saving materials; minimizing waste; enhancing recycling.”

Either telephone interviews followed by internet data collection or face-to-face interviews were carried out. Firms were randomly chosen from databases on industrial firms in each country (see next section). Considerable efforts were made to mobilize firms to respond to the survey. This required identifying the most appropriate person in each firm to answer the survey questions – it was determined that the questionnaire respondent was to at least have access to and participate in high-level meetings on strategic planning of the company.

3.2. Main features of national surveys

To extract firms from each country, a database containing a directorate of industrial firms, a methodology known as proportional probabilistic sampling, was used. This is the most recommended method to build samples of small dimensions. It relies on the specification of parameters. Out of three parameters, two must be defined; the third one remains as the adjustment variable. The parameters used in this study were the number of firms in the sample, the margin of error (the acceptable range for the estimated share of the population parameter) and the confidence level (probability that the true share will be within that range). This sampling technique is adequate for empirical exercises similar to the one carried out in this analysis.

Basic information about each of the national surveys is provided below.

3.2.1 Brazil

The survey was carried out between June and October 2017. A total of 1,250 Brazilian firms with at least 100 employees from all industrial sectors were targeted, including from the agroindustry (food products, beverages and tobacco), automobile (motor vehicles and auto parts), basic inputs (iron, steel, pulp, cement), capital goods (electrical machinery, machinery and equipment), chemicals (petrochemicals, rubber and plastic products), consumer goods (textiles, garments, footwear, durable goods), and information and communication technologies (office and computing machinery, communication instruments), among others. The confidence level was set at 90 per cent. The margin of error was not disclosed by the local provider of the survey services.[3]

Due to operational problems in conducting the survey, only 813 firms could be successfully surveyed. After a critical analysis of the collected questionnaires, a number of respondents were excluded due to inconsistencies, and the sample was ultimately reduced to 759 firms. Table 2 presents the composition of firms in Brazil's survey.

Table 2: Brazil: final sample by industry and size

Size	Number	%
Large (more than 500 employees)	204	26.9%
Medium – large (250-500 employees)	105	13.8%
Medium (100-250 employees)	168	22.1%
No answer	282	37.2%
Total	**759**	**100.0%**
Industry	**Number**	**%**
Agroindustry	117	15.4%
Capital goods	136	17.9%
Consumption goods	142	18.7%
Automobiles and auto parts	44	5.8%
Basic inputs	115	15.2%
Chemicals	109	14.4%
Information and communication technologies	35	4.6%
Others	61	8.0%
Total	**759**	**100.0%**

Source: I2027 Final Report (IEL/NC et al., 2018).

[3] This survey was part of a research project commissioned by the Brazilian Industrial Board Agency, Instituto Euvaldo Lodi to the Instituto de Economia, Universidade Federal do Rio de Janeiro (IEL/NC et al., 2018). The survey itself was the responsibility of CNI, which subcontracted the execution of the survey in accordance with their internal procedures.

3.2.2 Argentina

The survey in Argentina was conducted during the second half of 2018. A total of 307 firms from six industries in the manufacturing sector was included, namely from processed foods; steel; light vehicles and parts and accessories; textile; agricultural machinery; and biopharmaceuticals. The target number of firms to be surveyed in each industry was set to 50 firms. The dataset obtained from the collected questionnaires is summarized in Table 3. The statistical parameters were not available.

Table 3: Argentina: final sample by industry and size

Industry	Number of firms	Micro (%)	Small (%)	Small to medium (%)	Medium to large (%)	Large (%)
Food	47	30	34	15	15	6
Steel / mechanics	51	8	45	31	8	8
Light vehicles/parts	47	6	36	26	19	13
Textile	47	13	51	15	9	13
Agricultural machinery	52	17	46	21	8	8
Biopharma	49	14	20	27	10	29
Total	293	15	39	23	11	13

Source: Albrieu et al. (2019b).

3.2.3 Viet Nam

The Vietnamese survey was conducted in the first half of 2019 in collaboration with the National Center for Economic Forecast and Information (NCIF). The targeted firms in Viet Nam included industrial firms operating in selected industries (automotive, electronics, food and textiles). The firms were small (20-99 employees), medium-small (100-249 employees), medium-large (250-499 employees) and large (500 employees). They all operated in the regions of Hanoi and Ho Chi Minh.

The sample was fixed at 250 firms and the confidence level was 90 per cent. Table 4 indicates the margin of error of the estimation for the stratification adopted. The final sample comprised 268 firms, which met the original sample standards.

Table 4: Viet Nam: population, sample and margin of error by stratification

	Sample	Population	Margin of Error %
ISIC			
Automotive	57	369	10.0%
Electronics	61	621	10.0%
Food	64	1.199	10.0%
Textile	66	3.281	10.0%
Size			
Small	133	2.923	7.0%
Medium-small	49	1.077	11.5%
Medium-large	28	608	15.2%
Large	39	862	12.9%
Area			
Hanoi	111	1.845	8.60%
Ho Chi Minh	137	3.625	6.40%
Total	**248**	**5.470**	**5.10%**

Source: Authors' elaboration.

3.2.4 Ghana

The Ghanaian survey was conducted in the first half of 2019 in collaboration with the CSIR-Science and Technology Policy Research Institute. The strategy for extracting the sample of firms required adjustments due to the small number of firms with available information.

The first but inevitable adjustment was to exclude the industry "information and communication technologies" and "automotive and auto parts" due to the very small number of companies in the database. To increase the number of participating firms, firms from the following industries were included: furniture, metal products and plastic and rubber.

In very small samples such as the Ghana's, the usual proportional sampling method tends to lead to large variations in error margins. This can be an undesirable result as it might weaken the representativeness of the analysis. To avoid this problem in the extraction of the Ghanaian sample, a sample was created in which the same margin of error was applied to all surveyed industries. By setting the margin of error at 10 per cent for a 90 per cent confidence level, as was the case for Viet Nam, it was determined that 199 firms would be sufficient for Ghana's sample – a number that coincided with the survey goals.

Four different firm sizes based on the total number of employees were identified, namely:

- Small: 20-29 and 30-49 employees
- Medium: 50-99 employees
- Medium-large: 100-200 employees
- Large: more than 200 employees

To avoid an over-representation of small companies in the results, a binding constraint of no more than 50 per cent small firms was introduced in each industry (which applied in all cases). After adopting this parameter, the sample was defined as presented in Table 5.

Table 5: Ghana: population, sample and margin of error by stratification

	Population	Sample	Margin of Error %
ISIC			
Food products, beverages and tobacco	210	51	10.0%
Furniture and wood	90	39	10.0%
Metal products	99	40	10.0%
Plastic and rubber	68	34	10.0%
Textiles, textile products, leather and footwear	67	34	10.0%
Total	**534**	**199**	**4.6%**
Size			
Small	331	99	6.9%
Medium	82	41	9.1%
Medium-large	52	26	11.4%
Large	69	32	10.8%
Total	**534**	**199**	**4.6%**

Source: Authors' elaboration.

3.2.5 Thailand

The Thai survey was also conducted in the first half of 2019, with the financial and technical support of the Digital Economy Promotion Agency (DEPA), the Ministry of Digital Economy and Society. The extraction procedure of the sample in Thailand faced similar problems as in the Ghanaian case. Following the technique used in Ghana and Viet Nam, the number of firms required in each industry to create a sample that presented a homogeneous sectoral margin of error was estimated. Then, for a sample corresponding to a target of 200 companies, it was estimated that a margin of error of 9 per cent could be achieved for each industry. Based on this, the following distribution of company sizes into four groups based on the number of employees was specified:

- Small: 50-99 employees
- Medium: 100-249 employees
- Medium-large: 250-499 employees
- Large: more than 500 employees

Table 6: Thailand: population, sample and margin of error by stratification

	Population	Sample	Margin of Error %
ISIC			
Food	195	59	9.0%
Textiles, textile products, leather and footwear	85	43	8.9%
Electronics	157	55	9.0%
Automotive	86	44	8.7%
Total	**523**	**201**	**4.6%**
Size			
Small	333	100	6.9%
Medium	109	57	7.6%
Medium-large	45	25	11.3%
Large	36	19	13.3%
Total	**523**	**201**	**4.6%**

Source: Authors' elaboration.

As the number of large firms is relatively small, a strict proportional distribution of the firms in each industry according to size would lead to an underrepresentation of that group. Thus, the strategy adopted for the Ghana sample was replicated: to limit the number of small enterprises to a maximum of 50 per cent of the industry in the sample. The final result for the Thai sample is presented in Table 6.

3.3. Establishing a comparable dataset

The original database used in this study was constructed by compiling data obtained from independent field surveys conducted in five countries (Argentina, Brazil, Ghana, Thailand and Viet Nam). As mentioned above, the first survey was carried out in Brazil, followed by that in Argentina; in the other three countries, the surveys were entitled "Adoption of Digital Technologies by Industrial Firms" and were commissioned by and conducted under the guidance of UNIDO. As mentioned above, each survey differed, but they all included key questions on DT adoption patterns. Moreover, the Brazilian survey did not include questions on skills which all others did, while the Ghanaian, Thai and Vietnamese questionnaires were the most complete ones and included questions on sustainability. All surveys targeted industrial firms, which were then sampled and stratified according to industry and firm size, as discussed in the previous section.

As each survey had unique industry and size specifications, three essential methodological steps had to be introduced to build a comparable dataset and produce effective inter-country analysis results.

The first step was to extract firms from each country's original dataset based on the industry criteria, that is, firms operating within the same industry in each country were chosen. This strategy enabled the Brazilian and the Argentine samples to be converged with the industrial selection designed for the three country surveys sponsored by UNIDO.

The second step was to eliminate firms that had not responded to questions related to their current or their expected digital technology adoption for three or more of the five business functions specified in the questionnaire. This strategy was designed to ensure quality of the results and to mitigate possible incongruences in the responses. After applying these conditions to the database, the original aggregated dataset, consisting of 1,730 respondents, was reduced to a total of 1,158 firms. This sample represented the final number of firms from Argentina, Brazil, Ghana, Thailand and Viet Nam used in our comparative study.

Finally, the five-country sample was organized according to two structural variables: firm size and sectoral technology intensity. Two sizes were specified: large firms, with 100 employees or more, and small firms, with less than 100 employees. For sectoral technology industry, firms were classified as belonging to either high- or medium high-technology intensity industries (H-M-H), or to low- or medium low-technology intensity industries (L-M-L), as defined by the OECD.[4] The H-M-H group includes automobile and auto parts and electronics. No firms from Ghana were included in this category. The L-M-L group includes food and textile, and furniture, metal products and plastic in the case of Ghana only.

The final composition of the five-country sample is presented in Table 7, which shows the number of firms for each country by size and the sectoral technology intensity of the industrial activities.

[4] ISIC Rev.3 Technology Intensity Definition, https://www.oecd.org/sti/ind/48350231.pdf.

Table 7: Final sample by size and sectoral technology intensity

Country	Size	OECD_Sector		Total
		H-M-H	L-M-L	
Argentina	Large	22	16	38
	Small	58	75	133
	Total	**80**	**91**	**171**
Brazil	Large	193	135	328
	Small	-	-	-
	Total	**193**	**135**	**328**
Ghana	Large		59	59
	Small		138	138
	Total		**197**	**197**
Thailand	Large	69	36	105
	Small	45	50	95
	Total	**114**	**86**	**200**
Viet Nam	Large	73	84	157
	Small	49	56	105
	Total	122	140	262
Total		509	649	1158

Note: Large: 100 or more employees; Small: less than 100 employees. ** H-M-H: High- or Medium High-Technology Industry; L-M-L: Low- and Medium Low-Technology Industry.
Source: Authors' elaboration.

The comparative analysis conducted throughout the rest of this paper comprises three different dimensions: (i) current DT adoption, (ii) expected (five to ten years) DT adoption, and (iii) stage of execution of plans and actions to achieve the projected DT generation.

For each of the five business functions f_i (relations with clients and suppliers, product development, process management and business management), respondents indicated their firm's current and expected DT generation, as well as the nature of mobilization efforts currently being executed to reach expected future adoption. The current and expected DT generation of firms was thus the result of an inference from the use of DTs in each of the five specified business functions. Therefore, no question in the survey addressed the DT generation of the firm as a whole, that is, no respondent was directly asked to indicate which DT generation the firm as a unit of observation uses or expects to use. The deliberate choice of following the strategy of inference has two reasons. The first is an economic one and is related to a fundamental feature of industrial firms in developing countries: their intra-firm heterogeneity, as they may use DTs of different generations simultaneously in different business functions. The second one is of a statistical nature and is derived from the assumption that an analysis of various answers (current and expected DT generation for five business functions) might lead to a more consistent result than an analysis based on only one observation.

Thus, in order to design and build a synthetic index for DT generation of the firm as a whole, considering the answers for each $\boldsymbol{f_i}$., three aggregated indexes were developed:

(i) Firm_c for current DT generation,

(ii) Firm_e for expected DT generation, and

(iii) Firm_a for mobilization efforts.

The procedure to build the three indexes followed similar criteria. First, the smallest value of $\boldsymbol{f_i}$ was disregarded as it was assumed that the firm could not adopt a business model requiring DT for all five business functions. This is the case, for instance, of firms that produce on demand following an OEM model, and which might therefore not require any further investments in product design. Another example are firms operating as sub-contractors that do not need well-developed costumer relationships.

The next step in the construction of the firm aggregate index was to sum up the values of the four remaining $\boldsymbol{f_i}$. This allowed us to establish the aggregate DT generation of a firm according to a range of limit values as defined below.

Call $\mathbf{Sum_c}$ the index that aggregates all $\boldsymbol{f_{i\_}c}$ for the **current** digital adoption of the firm:

$$(1)\ \mathrm{Sum_c} = \sum_{i=1}^{5} f_{i\_}c\ - \min\{f_{i\_}c\}, where\ 4 \leq \mathrm{Sum_c} \leq 16$$

The synthetic grade for the current adoption of the firm is derived from:

$$(2)\ \mathrm{Firm}_c = \begin{cases} 1 = if\ 4 \leq \mathrm{Sum_c}\ \leq 6 \\ 2 =\ if\ 7 \leq \mathrm{Sum_c}\ \leq 9 \\ 3 = if\ 10 \leq \mathrm{Sum_c}\ \leq 12 \\ 4 = if\ 13 \leq \mathrm{Sum_c}\ \leq 16 \end{cases}$$

The same procedure was applied to expected DT generation (Firm_e) and to aggregate mobilization effort level (Firm_a). These indexes served as the basis for the development of indicators conceived for an inter-country comparative analysis. These indicators are specified in Section 4.1.

4. Comparing digitalization among selected developing countries: The perspective from firm-level data

This section presents and discusses the results of the surveys carried out in Argentina, Brazil, Ghana, Thailand and Viet Nam. As mentioned previously, they all share common features, but specific measures were introduced to establish a comparable data sample.

This section addresses two issues. Firstly, the focus of the analysis is on the adoption of DTs by firms, either at present (Current Digital Adoption Ratio -DAR_C) or in the near future (Expected Digital Adoption Ration -DAR_E). On this basis, how firms are currently preparing for the future they project by means of a Digitalization Readiness Index (DRI) will be examined. DRI combines current and future adoption levels based on mobilization efforts. Secondly, the implications of the current and projected adoption of DTs on employment and skills as well as energy use and sustainability will be discussed.

The analysis is developed along three levels: at the national, firm size and sectoral technology intensity of firms. As previously explained, in terms of size, firms are separated into two groups: (i) large (100 or more employees), and (ii) small firms (less than 100 employees). Two broad groups are distinguished based on the OECD's definition of technology intensity: (i) high- and/or medium high-technology intensity industries (H-M-H), and (ii) low- and/or medium low-technology intensity industries (L-M-L).

Section 4.1 explains the indicators proposed for the empirical analysis.

4.1. Indicators: digital adoption ratio (DAR) and digitalization readiness index (DRI)

The comparative analysis is based on two indicators. Both are developed from the synthetic indexes ($\text{Firm}_c, \text{Firm}_e$ *and* Firm_a) already explained in Section 3.3.

1. **Digital adoption ratio (DAR)**. This is an indicator designed to measure the share of adoption of each generation (**g=1,..,4**) of digital technology for a specific group of firms (country, size, sector). It refers to the share of firms that have Firm_c or $\text{Firm}_e = 1$ to 4 in comparison to the total number of firms of each group. It can be measured for the **current** adoption (DAR_c^g) as well as for the **expected** adoption rate in ten years (DAR_e^g).

$$\text{(1a) } \text{DAR}_c^g = \frac{N° \; of \; firms \; in \; current \; DT \; generation \; g}{Total \; of \; firms \; \text{(country,size,sector)}} \%$$

$$\text{(1b) } \text{DAR}_e^g = \frac{N° \; of \; firms \; in \; expected \; DT \; generation \; g}{Total \; of \; firms \; \text{(country,size,sector)}} \%$$

2. **Digitalization Readiness Index (DRI).** This is a synthetic indicator that combines the firm's current and expected DT generation with the measures the firm is currently undertaking to achieve the desired DT generation in the future. The indicator reveals a firm's course of action as a measure of the probability of its effectiveness to reach the projected DT generation. The expression of DRI is as follows:

$$(2)\ DRI = \ \text{Firm}_c + (\text{Firm}_e - \text{Firm}_c) * \alpha$$

Where α is an action parameter defined as $(\text{Firm}_a - 1)/3$, which is 0 if $\text{Firm}_a = 1$ (no action); 0.33 if $\text{Firm}_a = 2$ (reviewing); 0,66 if $\text{Firm}_a = 3$ (have a plan)and 1 if $\text{Firm}_a = 4$ (have a plan that is being executed). A constraint was deliberately built into the indicator: a firm cannot jump three generations (i.e. a firm that is currently using first generation technologies and intends to reach fourth generation DTs within the next five to ten years), even if plans are already being implemented to achieve the expected technology generation.

Classifying firms according to their readiness level is more relevant for this analysis than the absolute value of the DRI index, as it immediately depicts the position of the country and its set of firms organized by sectoral technology intensity or size.

That said, three categories (or $DRI\ Positions$) inspired by Abramovitz (1986) were defined based on the digitalization position of the firms: Category 1 covers firms located in a backward position in terms of their current and future DT adoption and mobilization efforts (mostly G1 and/or G2 or G3 and/or G4, but with no significant mobilization efforts). These firms are **lagging behind**. Category 2 defines firms that will be using at least G3 and/or G4 technologies in the projected future and have implements some mobilization efforts. These firms are **catching up.** Category 3 encompasses all firms that will be using G4 technologies in the future and undertake consistent mobilization efforts as they have currently already adopted G2 or G3 technologies. These firms are **forging ahead.**[5]

Chart 1 summarizes the map implemented by the algorithm developed for estimating firms' readiness positions.

[5] The threshold for DRI Position was set as follows: if DRI is less than or equal to 2, then the DRI Position is 1; if the DRI is greater than 2 but less than 4, the DRI Position is 2; and, finally, if the DRI is greater than or equal to 4, then the DRI Position is 3.

Chart 1. Dri position according to firm_c, firm_e and firm_action

Firm_C	FIRM_E	FIRM_ACTION			
		1- No Action	2 - Studying	3- Have a Plan	4- Executing a Plan
G1	G1	L	L	L	L
	G2	L	L	L	L
	G3	L	L	C	C
	G4	L	L	C	C
G2	G2	L	L	L	L
	G3	L	L	C	C
	G4	L	L	C	F
G3	G3	C	C	C	C
	G4	C	C	F	F
G4	G4	F	F	F	F

Note: L = lagging behind; C= catching up; F = forging ahead
Source: Authors' elaboration.

The next section analyses the indicators described above to draw a comparative picture of the countries, focussing on how DAR_c^g, DAR_e^g and $DRI\ position$ perform according to size and sectoral technology intensity.

4.2. Comparing countries: current and expected adoption of digital technologies

4.2.1 Digitalization at country level: significant projected progress in the future, departing from very basic levels

Tables 8 and 9, as well as Figures 1 and 2, provide country-level comparable data on current and expected DT adoption by industrial firms from Argentina, Brazil, Ghana, Thailand and Viet Nam.

The overall picture of current adoption is quite straightforward: the majority of firms in the five-country sample are lagging behind relative to more advanced DTs. Table 8 and Figure 1 show that 60.4 per cent and 26.8 per cent of firms from all countries have adopted G1 and G2 technologies, respectively. Only 1.6 per cent of the 1,158 firms in the sample, or 18 firms, declared that they had adopted the most advanced DTs available. However, there are differences among countries: in Brazil, one-third of the firms use G3 or G4 technologies; in Argentina, around 20 per cent of firms do; whereas firms in Ghana, Thailand and Viet Nam lag further behind, with 90 per cent using G1 or G2 technologies. Only 3.7 per cent of Brazilian firms, 2.9 per cent of Argentine firms and 0.4 per cent of Vietnamese firms have adopted the most advanced DTs; no firms from Ghana or Thailand use G4 technologies.

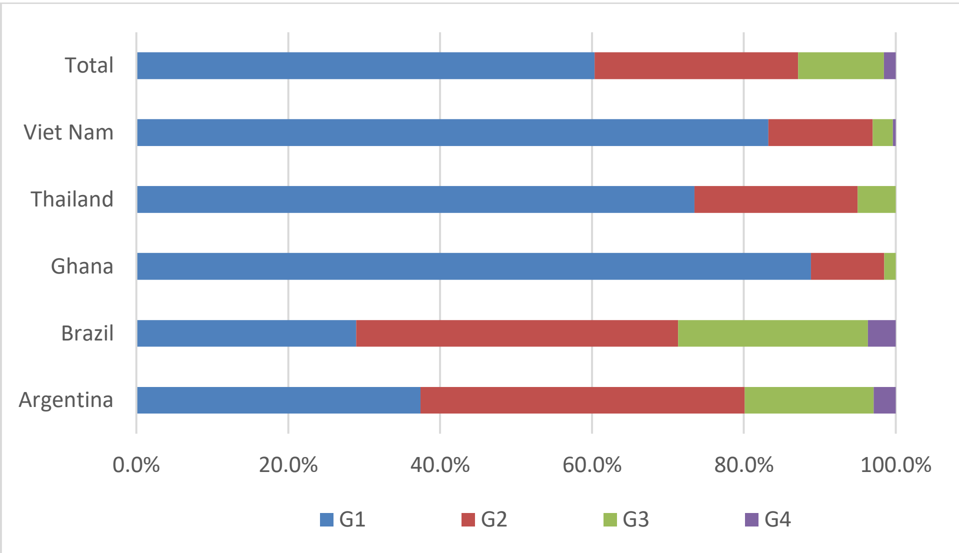
The adoption of G1 or G2 technologies means that the majority of firms from Argentina, Brazil, Ghana, Thailand and Viet Nam are currently using these technologies for specific purposes, in specific business functions (for example, CAD in product development), or to link up two or more business functions (CAD-CAM for product development and production processes). Differences among and within countries are not significant.

Table 8: Current digital adoption ratio, country level - dar_c country

	Digital Generation			
Country	**G1**	**G2**	**G3**	**G4**
Argentina (n= 171)	37.4%	42.7%	17.0%	2.9%
Brazil (n= 328)	29.0%	42.4%	25.0%	3.7%
Ghana (n= 197)	88.8%	9.6%	1.5%	0.0%
Thailand (n= 200)	73.5%	21.5%	5.0%	0.0%
Viet Nam (n= 262)	83.2%	13.7%	2.7%	0.4%
Total (n = 1,158)	**60.4%**	**26.8%**	**11.3%**	**1.6%**

Source: UNIDO/IE-UFRJ database based on country-level surveys.

Figure 1: Current digital adoption ratio, country level



Source: UNIDO/IE-UFRJ database based on country-level surveys.

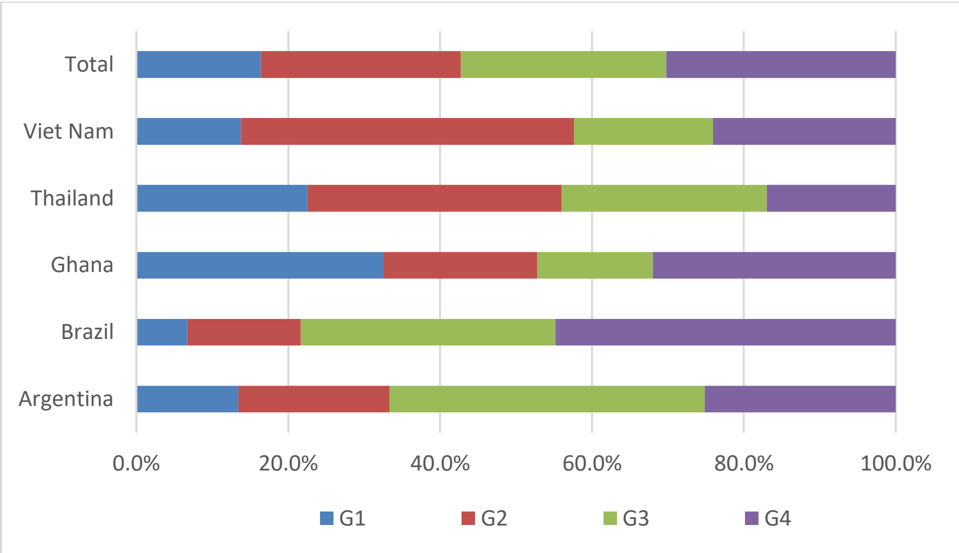
The five-country projections for the future (Table 9, Figure 2), however, indicate that the firms expect to achieve considerable progress compared with their current adoption levels and increasing differences among and within countries are evident.

Table 9: Expected digital adoption ratio, country level

	Digital Generation			
Country	**G1**	**G2**	**G3**	**G4**
Argentina (n= 171)	13.5%	19.9%	41.5%	25.1%
Brazil (n= 328)	6.7%	14.9%	33.5%	44.8%
Ghana (n= 197)	32.5%	20.3%	15.2%	32.0%
Thailand (n= 200)	22.5%	33.5%	27.0%	17.0%
Viet Nam (n= 262)	13.7%	43.9%	18.3%	24.0%
Total (n = 1,158)	**16.4%**	**26.3%**	**27.0%**	**30.2%**

Source: UNIDO/IE-UFRJ database based on country-level surveys.

Figure 2: Expected digital adoption ratio, country level



Source: UNIDO/IE-UFRJ database based on country-level surveys.

Firstly, over half of the firms (57.2 per cent) from the five-country sample hope to adopt G3 or G4 in the upcoming years. That is, the majority of firms from Argentina, Brazil, Ghana, Thailand and Viet Nam project a future in which DT will be used to integrate and interconnect all business functions (G3) and to-integrate, connect and use very advanced DTs to support and even take over decision-making processes (G4). To move from G1/G2-dominated environment to a G3/G4 projected scenario is not, however, straightforward. As mentioned in Chapter 2, for a firm to evolve towards G3 or even G4, it must initiate major organizational changes to integrate business functions. Such evolution requires a comprehensive and effective standardization of processes, the implementation of information systems, as well as the development of core high-level competences to effectively use and exploit the full potential of advanced communication devices, big data and artificial intelligence, among others.

Secondly, pronounced differences among and within the five countries must be highlighted. The highest positive future projections are found in the Brazilian sample: while presently, 71.4 per cent of firms use G1 and G2 technologies, 44.8 per cent of the surveyed firms hope to have introduced G4, 33.5 per cent G3, and only 21.6 per cent either G1 or G2 technologies in the future. Such marked advances are also partially found in Argentina. One quarter of the sample expects to have adopted G4 technologies over the next five to ten years compared to 2.9 per cent of firms that are currently using them. In addition, while 80.1 per cent are currently using G1 and/or G2 technologies, this group of firms is presumed to shrink to 33.4 per cent in the future. The contrast within the five-country group intensifies relative to the current adoption levels. While over 90 per cent of firms from Ghana, Thailand and Viet Nam are currently using G1 and/or G2 technologies, their share is expected to decrease to just about 50 per cent in the future. Moreover, 32 per cent of Ghanaian firms expect to have reached the most advanced DT generation in the near future compared with 17 per cent and 24 per cent of firms from Thailand and Viet Nam, respectively.

In short, when the current and future DT levels are compared, the surveyed firms expect to achieve considerable progress in DT adoption. Following this projected trajectory will not be easy, as progress along the succession of DT generations is not linear and requires substantial modifications to the nature of competences as well as to firms' organizational structures. This means that firms that project that they will make advances in DT over the next five to ten years in relation to their current adoption levels, should already be planning and perhaps even implementing measures to achieve their intended goals.

The five-country sample also suggests that diversity and heterogeneity exist among and within countries. To examine the evidence of diversity and heterogeneity in more depth, the following two sub-sections evaluate the adoption patterns in relation to two structural features of firms: size and sectoral technology intensity.

4.2.2 Digitalization according to firm size: the larger the firm's size, the more advanced its technology generation

To further explore the country-level patterns of DT adoption, Tables 10 and 11 highlight the differences between the current and expected adoption of DTs according to firm size. To normalize the evidence from the different surveys, two size ranges of firms are taken into consideration: small (less than 100 employees) and large (100 +). Such a differentiation was not possible for Brazil as only firms with 100 employees and above were surveyed.

The overall picture is relatively clear: larger firms more frequently adopt and, more importantly, expect to adopt more advanced technology generations relative to their smaller peers. This result does not come as a surprise, as larger firms are presumed to have more information about and resources to invest in modernization. If DT adoption strengthens competitiveness, the higher probability of larger firms adopting more advanced DTs would eventually contribute to reinforcing their already strong market positions. However, as will be seen, this general assumption does not apply to Thailand and Viet Nam, as small firms in those countries project a fairly similar trajectory for the future.

An inter-country comparison of current DT adoption (Table 10) indicates common and specific features. As mentioned in the previous sub-section, most firms from all countries have already adopted G1 and G2 technologies. However, in Ghana, Thailand and Viet Nam, large firms currently tend to view themselves in a slightly more advanced position than small firms do: the concentration of small firms that use G1 technologies is higher, while there are more large firms than small ones that use G2 technologies. This finding is even more marked in Argentina, where 10 per cent of large firms use G1 technologies compared to 45 per cent of small firms. By contrast, while the share of firms that use G2 technologies is similar (around 40 per cent), 34.2 per cent of large firms claim that they are already using G3 technologies compared to only 12.0 per cent of small firms; only 7.9 per cent of large and 1.5 per cent of small firms have already adopted the most advanced DTs, i.e. G4.

Differences among countries are even more pronounced when firm size and expectations for the next five to ten years are considered and contrasted with the current DT adoption (Table 11). In the case of Argentina, large firms intend to shift from currently G2 and G3 (47.4 per cent and 34.2 per cent, respectively) to G3 and G4 in the future (42.1 per cent and 52.6 per cent, respectively). Meanwhile, 86.5 per cent of small firms currently use either G1 or G2 technologies and, in the future, most firms (65.4 per cent) will be using G2 and G3 technologies, and only 17.3 per cent will have adopted G4 technologies.

Table 10: Current digital adoption ratio. Size of firms

		Digital Generations			
Country	**Size***	**G1**	**G2**	**G3**	**G4**
Argentina	Large (n= 38)	10.5%	47.4%	34.2%	7.9%
Argentina	Small (n= 133)	45.1%	41.4%	12.0%	1.5%
Brazil**	Large (n= 197)	28.9%	42.4%	25.0%	3.7%
Ghana	Large (n= 59)	79.7%	16.9%	3.4%	0.0%
Ghana	Small (n= 138)	92.8%	6.5%	0.7%	0.0%
Thailand	Large (n= 105)	63.8%	31.4%	4.8%	0.0%
Thailand	Small (n= 95)	84.2%	10.5%	5.3%	0.0%
Viet Nam	Large (n= 157)	77.7%	17.2%	4.5%	0.6%
Viet Nam	Small (n= 105)	91.4%	8.6%	0.0%	0.0%

Note: * Large: 100 or more employees; Small: less than 100 employees. ** In the Brazilian survey, only firms with 100 and more employees were surveyed.

Source: UNIDO/IE-UFRJ database based on country-level surveys.

This stepwise Argentine pattern is also found in Thailand and Viet Nam, even though expectations for the future are less pronounced. Currently, over 90 per cent of firms in Thailand and Viet Nam are using either G1 or G2 technologies, regardless of size. In the future, the majority of large Thai firms (69.5 per cent) expect to adopt either G2 or G3 and close to 20 per cent of firms aim to introduce G4 technologies in the next five to ten years. By contrast, 69.5 per cent of small firms in Thailand will continue to use either G1 or G2 technologies.

In Viet Nam, the pattern is similar, with large firms expecting to be using G2 or G3 and small firms using G1 or G2 technologies in the future. What is notable for Viet Nam and Thailand are the relatively small differences between firms' expectations towards adopting G4 technologies in the future according to size: 19.1 per cent for larger and 14.7 per cent for smaller firms in the case of Thailand and 22.3 per cent for larger and 26.7 per cent for smaller firms in the case of Viet Nam. Even if the differences are not particularly large, Viet Nam is the only country where small firms' expectations of introducing more advanced DTs are higher than the expectations of large firms.

Finally, a dichotomic pattern prevails in Ghana. While over 90 per cent of firms currently use G1 or G2 technologies, with a bigger share of large firms using G2 (31.43 per cent compared to 10.53 per cent small firms), expectations of the future show a higher proportion of large firms aiming to adopt either G2 (25.4 per cent) or G4 (39.0 per cent). By contrast, 38.4 per cent intend to remain at G1 and, at the other extreme, 29.0 per cent of firms expect to adopt the most advanced DTs (G4).

Table 11: Expected digital adoption ratio. Size of firms

		Digital Generations			
Country	**Size***	**G1**	**G2**	**G3**	**G4**
Argentina	Large (n= 38)	0.0%	5.3%	42.1%	52.6%
Argentina	Small (n= 133)	17.3%	24.1%	41.4%	17.3%
Brazil**	Large (n= 197)	6.7%	14.9%	33.5%	44.8%
Ghana	Large (n= 59)	18.6%	25.4%	16.9%	39.0%
Ghana	Small (n= 138)	38.4%	18.1%	14.5%	29.0%
Thailand	Large (n= 105)	11.4%	32.4%	37.1%	19.1%
Thailand	Small (n= 95)	34.7%	34.7%	15.8%	14.7%
Viet Nam	Large (n= 157)	10.8%	44.6%	22.3%	22.3%
Viet Nam	Small (n= 105)	18.1%	42.7%	12.4%	26.7%

Note: * Large: 100 or more employees; Small: less than 100 employees. **In the Brazilian survey, only firms above 100 employees were interviewed

Source: UNIDO/IE-UFRJ database based on country level surveys.

In summary, when firm size is taken into consideration, more differences in the patterns of digital adoption among and within countries is exposed. Size matters when trying to differentiate the extent to which firms adopt and expect to adopt DTs: the larger the firm, the higher the propensity to adopt more advanced technological generations, with the exception of the case of Viet Nam. This shows that each country has a unique pattern of adoption and development path towards the future. It is beyond the scope of the present study to further analyse the reasons for these differences. At this stage, the only possible preliminary implication is that not only must both private and public policies pay close attention to DTs, the specific measures must also be embedded in the local environment to increase the chances of greater effectiveness.

The following section sheds light on another structural feature of the five-country panel-the sectoral technology intensity of firms to identify further implications.

4.2.3 Digitalization according to sectoral technology intensity of firms: the higher technology intensiveness, the more advanced the level of digitalization

As previously mentioned, the five-country panel was divided into two groups: 1) firms belonging to high- or medium high-technology intensity industries, and 2) firms belonging to low- or medium low-technology intensity industries, as defined by the OECD. These groupings were applied to Argentina, Brazil, Thailand and Viet Nam, but not for Ghana, where all firms belonged to low- or medium low-technology intensity industries.

Results on current and expected DT adoption are presented in Tables 12 and 13, respectively. The overall pattern is similar to that observed for firm size and again, it comes as no surprise: the higher the technology intensity of firms, regardless of country, the more advanced they are likely to be in the current adoption of advanced DTs. Likewise, the high- and medium high-technology intensity of firms intend to adopt more advanced DTs in the future than firms with a lower technology intensity.

Currently, as shown in Table 12, the concentration at G1 is very marked in Thailand and Viet Nam, regardless of the firms' sectoral technology intensity, though the proportion of high-technology firms using G1 technologies is slightly lower: 67.5 per cent of medium high- and high-technology firms use G1 technologies versus 81.4 per cent of low- and medium-technology industries in Thailand and 77.1 per cent and 88.6 per cent, respectively, for Viet Nam.

In Argentina and Brazil, around 40 per cent of firms in both groups of sectors have adopted G2 technologies. Differences emerge with regard to the adoption of G3 technologies by firms of each sectoral technology intensity group and countries. While the share of high- and medium high-technology firms is similar in both countries (between 28 per cent and 26 per cent), that of low- and medium low-technology intensive firms differs. In Argentina, a significant amount (43.9 per cent) of low- and medium low-technology firms have adopted G1 and only 6.6 per cent use G3 technologies. In Brazil, one- third of firms in the low- and medium low-technology group declared that they use G1 and 23 per cent stated that they use G3 technologies. That is, low- and medium low-technology firms in Brazil seem to be farther ahead than their counterparts in Argentina, as well as in Ghana, Thailand and Viet Nam.

In the future (Table 13), significant progress is expected, especially by high- and medium high-technology firms: only a small proportion (between 4.7 per cent and 14 per cent) of firms from Argentina, Brazil, Thailand and Viet Nam expect to remain at G1 level and between 20.2 per cent and 50.2 per cent expect to adopt G4 DTs. Country-based differences among low- and medium low-technology firms is higher. In Brazil, 9.6 per cent of low- and medium low-technology firms expect to continue using G1 technologies in the future; in Argentina and Viet Nam, it is 5 per cent of firm; and in Thailand, 33.7 per cent of firms expect to remain at G1 level in the next five to ten years.

Table 12: Current digital adoption ratio. Sectoral technology intensity of firms

		Digital Generation			
Country	**Sector***	**G1**	**G2**	**G3**	**G4**
Argentina	H or M-H (n= 80)	30.0%	40.0%	28.7%	1.3%
Argentina	L or M-L (n= 91)	43.9%	45.1%	6.6%	4.4%
Brazil	H or M-H (n= 193)	28.5%	40.9%	26.4%	4.2%
Brazil	L or M-L (n= 135)	29.6%	44.4%	23.0%	3.0%
Ghana**	L or M-L (n= 197)	88.8%	9.7%	1.5%	0.0%
Thailand	H or M-H (n= 114)	67.5%	27.2%	5.3%	0.0%
Thailand	L or M-L (n= 86)	81.4%	13.9%	4.7%	0.0%
Viet Nam	H or M-H (n= 122)	77.1%	17.2%	4.9%	0.8%
Viet Nam	L or M-L (n= 140)	88.6%	10.7%	0.7%	0.0%

Note: * Sectoral classification based on OECD sectoral technology intensities: H or M-H: High- or Medium High-Technology Industries; L or M-L: Low- and Medium Low-Technology Industries. ** In the Ghanaian survey, only Low- and Medium Low-Technology firms were interviewed

Source: UNIDO/IE-UFRJ database based on country-level surveys.

A similar development in the future is assumed by firms in both Argentina and Brazil. Future expectations in these two countries indicate that between 65 per cent and 80 per cent of firms will have adopted G3 or G4 over the next five to ten years, regardless of current sectoral technology intensity. This would be quite remarkable progress as only between 11 per cent and 30 per cent of firms are currently at a similar stage of adoption. Even so, differences between these two countries and sectoral technology intensity will prevail if the firms' expectations are fulfilled. In Argentina, the difference between high- and medium high-technology and low- and medium low-technology firms expecting to adopt G4 in the future is less marked than in Brazil: 27.5 per cent and 23.0 per cent in Argentina, compared to 50.2 per cent and 37.0 per cent in Brazil.

In Thailand, high- and medium high-technology firms are currently concentrated in G1 and G2 technologies (84.7 per cent of the sample). In five to ten years, most firms in this group (65.8 per cent) plan to move towards the adoption of G2 and/or G3 technologies. Most low- and medium low-technology firms expect to remain either at the G1 or G2 level (66.3 per cent), and only 12.8 per cent of firms from this group project that they will be using G4 technologies in the future. In Viet Nam, the development pattern is not straightforward. While most firms currently use G1 technologies (77.1 per cent of high- and medium high-technology and 88.6 per cent of low- and medium low-technology firms), expectations for the future vary across sectoral technology intensity. One-third of high- and medium high-technology firms expect to be at the G2 level over the next five to ten years, and 43.4 per cent expect to be using G4 technologies; in the low- and medium low-technology segment, over 50 per cent of the sample expect to reach the G2 level, while only 7.2 per cent see themselves using G4 technologies in the future.

Table 13: Expected digital adoption ratio. Sectoral technology intensities of firms

		Digital Generation			
Country	**Sector***	**G1**	**G2**	**G3**	**G4**
Argentina	H or M-H (n= 80)	10.0%	21.2%	41.3%	27.5%
Argentina	L or M-L (n= 91)	16.5%	18.7%	41.8%	23.0%
Brazil	H or M-H (n= 193)	4.7%	14.5%	30.6%	50.2%
Brazil	L or M-L (n= 135)	9.6%	15.6%	37.8%	37.0%
Ghana**	L or M-L (n= 197)	32.5%	20.3%	15.2%	32.0%
Thailand	H or M-H (n= 114)	14.0%	34.2%	31.6%	20.2%
Thailand	L or M-L (n= 86)	33.7%	32.6%	20.9%	12.8%
Viet Nam	H or M-H (n= 122)	11.5%	29.5%	15.6%	43.4%
Viet Nam	L or M-L (n= 140)	15.7%	56.4%	20.7%	7.2%

Notes: * Sectoral classification based on OECD sectoral technology intensities: H or M-H: High- or Medium High-Technology Industries; L or M-L: Low- and Medium Low-Technology Industries. ** In the Ghanaian survey, only low- and medium low-technology firms were interviewed.

Source: UNIDO/IE-UFRJ database based on country-level surveys.

4.3. Where firms stand: forging ahead, catching up or lagging behind? Mostly lagging behind, but country profiles differ

The previous sections examined and compared patterns of DT adoption to identify similarities and differences between countries and the structural features of firms (size and sectoral technology intensity) at a relatively high level of aggregation.[6] Taking the main concepts and the analytical framework presented in Chapter 2 as references, the preceding sections provided sufficient evidence to affirm that country, sectoral technology intensity, size and expectations of firms matter when it comes to differentiating patterns of DT adoption in Argentina, Brazil, Ghana, Thailand and Viet Nam. To take the analysis one step further, this section investigates how firms are preparing for the future they project for themselves.

At the country aggregate level, the evidence clearly shows that firms from developing countries are reserved, to say the least, with respect to the current adoption of DTs; when projecting the future, firms expect to make a significant leap. This is good news, but such expectations should be grounded on concrete actions as developing from lower technology generations to more

[6] This was necessary to allow for sound comparability but, as a result, the depth of analysis and derived implications were impaired by this technical constraint.

advanced DTs is not a linear process, as significant changes to organizational structures and capabilities are necessary. Thus, the nature of current mobilization efforts being undertaken by firms to prepare for the future must be investigated.

This issue is addressed in this section. To examine firms' mobilization efforts, their current and expected DT adoption levels are associated with ongoing measures to pursue such goals, which is represented by the Digital Readiness Index (section 4.1). In relation to the projected DT generation, firms were asked whether currently: (i) no current action is in motion; (ii) studies are being carried out; (iii) measures are being planned, or (iv) plans are underway; concrete action is being taken to build the future. It is thus assumed that different mobilization efforts may indicate how expectations are "anchored" in various types of action, indicating a lower or higher probability of firms to be effectively able (or not) to achieve the projected DT generation. The link between the current and expected adoption of DTs with the ongoing mobilization efforts is the rationale behind the Digital Readiness Index (DRI), as previously explained in the first section of this chapter.

Also, as previously mentioned, the three levels of digital readiness inspired by Abramovitz (1986) were devised to stylize where firms find themselves at: lagging behind, catching up or forging ahead (or moving forward). Not only are the current and expected adoption ratios of firms that are lagging behind relatively low, their current mobilization efforts in preparation of the future are minimal, if they exist at all. The aim of firms catching up is to develop from less to more advanced DTs in the future, but mobilization efforts to prepare for such future is at an infant stage. In the case of firms forging ahead, not only are they currently departing from a more advanced DT generation and intend to develop even further in the future, they are also presently and effectively engaged in preparing for the future or have already taken action to their high expectations.

Table 14 and Figure 3 provide an aggregate, country level view of the results obtained from the Digital Readiness Index. The aggregate result is quite straightforward: 63.9 per cent of firms from the five-country sample are lagging behind; 38.8 per cent are trying to catch-up; and only 7.3 per cent, or 84 firms out of the 1,158 sample, can be classified as forging ahead: firms that have adopted more advanced technologies compared to their peers and seek to evolve even further in the future, with plans already being executed to reach a projected future.

The pyramids in Figure 3 provide a visual perspective of the differences between and within countries. A metaphor of naval vessels can be used to further appreciate the different patterns:

- The pyramids of Argentina and Viet Nam are similar, resembling a ship. The hull constitutes a large base where firms that are lagging behind are located at; an intermediate deck of a smaller group of firms that are catching up, and an upper deck for the elite firms that are forging ahead (between 5 per cent to 7 per cent of the total of these two countries).
- Ghana's and Thailand's pyramids are also similar, but their pyramid resembles a submarine: a very large hull formed by firms that are lagging behind (between 80 per cent and 90 per cent of the respective samples); the conning tower represented by firms that are catching up (between 8 per cent and 18 per cent of the samples) and a periscope where 1 per cent of the firms from each country can be considered as moving forward.
- The Brazilian pattern differs, resembling a naval platform, with the middle section (47.3 per cent of firms that are catching up) representing the backbone of the floating platform, the bottom section functioning as a stabilizing force (37.2 per cent of firms lagging behind), and the top deck formed by firms that are forging ahead (15.5 per cent of the Brazilian sample).

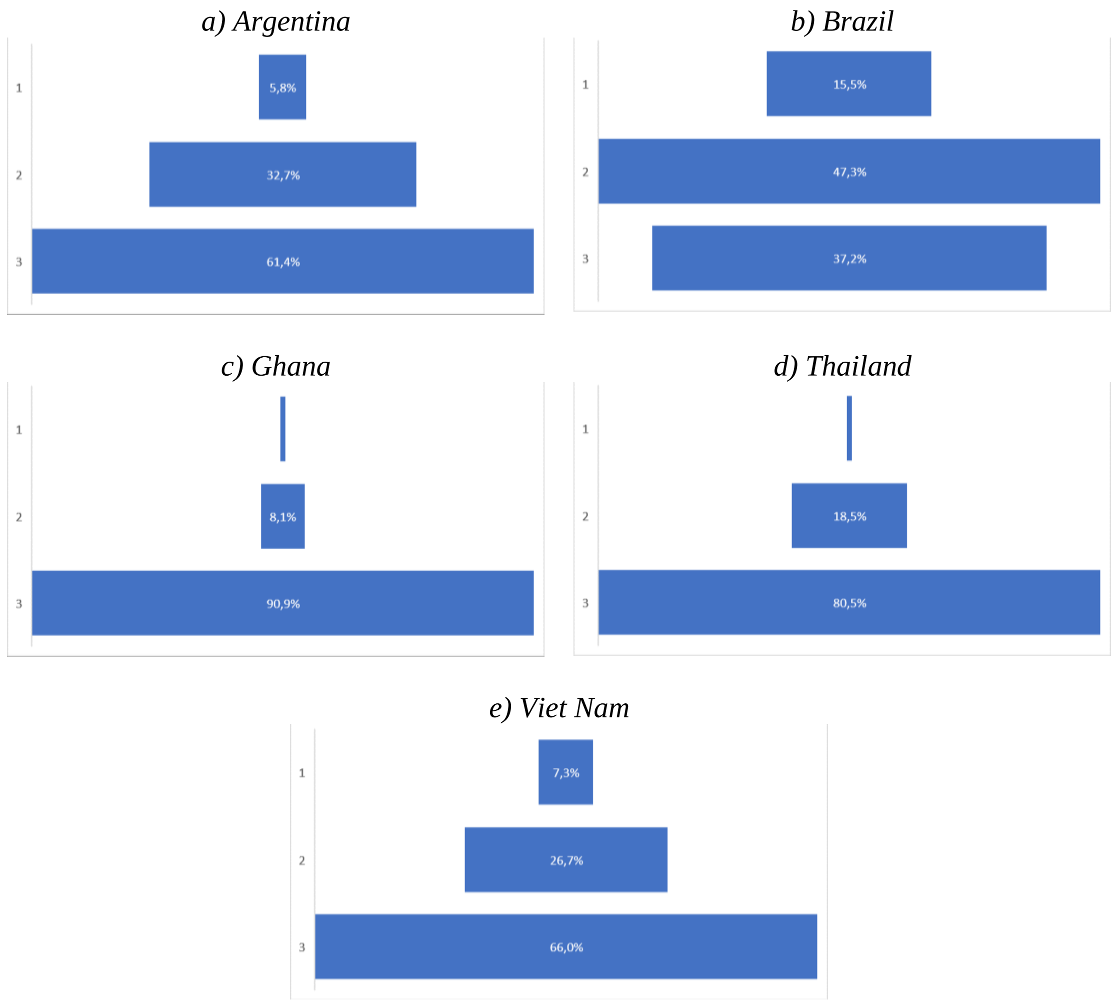
Further consideration of the nature of diversity and heterogeneity of this five-country sample can be expressed by means of such a naval vessel metaphor. Ghana's and Thailand's submarine profiles indicate that they have a very large share of firms that are lagging behind, a small proportion of firms that are catching up and a minority of firms that are moving forward. A trickle-down effect is less probable in a submarine profile than in the ship or naval platform profiles. In addition, the elite firms that are forging ahead may face difficulties in implementing their strategies due to the lack of a digital ecosystem to facilitate their immersion into the world of more advanced technologies. In this respect, the Brazilian naval platform profile may be more conducive to progress than the submarine and ship profiles, as its middle section, concentrated with firms that are catching up, dominates the others, thus providing a relatively solid base for the evolution of all groups of firms, including those lagging behind. The ship profiles of Argentina and Thailand finds resonance in a relatively traditional three-layer economic—or even social—structure: a large base of firms that are lagging behind, a significant middle layer of catching-up firms and a smaller share of elite firms at the top. Whether positive inducement effects from top to bottom will occur in the years to come remains an open, but unpredictable possibility.

Table 14: Digital readiness index. Country level

Country	Lagging Behind	Catching Up	Forging Ahead
Argentina (n= 171)	61.4%	32.7%	5.8%
Brazil (n= 328)	37.2%	47.3%	15.5%
Ghana (n= 197)	90.9%	8.1%	1.0%
Thailand (n= 200)	80.5%	18.5%	1.0%
Viet Nam (n= 262)	66.0%	26.7%	7.3%
Total (n = 1,158)	**63.9%**	**28.8%**	**7.3%**

Source: UNIDO/IE-UFRJ database based on country-level surveys.

Figure 3: Digital readiness position by country



Note: 1 – Lagging Behind; 2 – Catching Up; 3 – Forging Ahead.
Source: UNIDO/IE-UFRJ database based on country-level surveys.

With the already mentioned caveat that the Brazil survey does not include firms with less than 100 employees, Table 15 relates the Digital Readiness Index to the size of firms. The figure is similar to the one already depicted in relation to the Digital Adoption Ratio, in previous sections. Firstly, regardless of size, most firms in practically all countries lag behind. Secondly, larger firms perform better than their smaller peers in all countries, though there are some country specificities:

- In Argentina, a small share of larger firms is moving forward (13.2 per cent) and most of the firms are catching up (55.3 per cent); by contrast, 69.9 per cent of small firms are lagging behind, 26.3 per cent are catching up and only 3.8 per cent are forging ahead;
- In Ghana, the differences in terms of firm size are less pronounced; 83.1 per cent of large and 94.2 per cent of small Ghanaian firms are lagging behind; only 3.4 per cent of large firms are moving forward while none of the small firms are forging ahead;
- In Thailand, while the majority of firms are lagging behind, regardless of size, nearly a quarter of large firms are catching up in contrast to only 12.6 per cent of small firms;
- In Viet Nam, even if most firms are lagging behind (63.1 per cent of large and 70.5 per cent of small firms), 26 per cent of all firms surveyed (both sizes) are catching up; a smaller share of large firms (10.2 per cent) are moving forward, while an even smaller one of small firms (2.9 per cent) are forging ahead.

Regarding sectoral technology intensity (with the exception of the Ghanaian case, where no firms belonging to high- or medium high-technology industries took part in the survey), as illustrated in Table 16, the overall picture is similar to what was found concerning the adoption ratios: firms from high- and medium high-technology industries are better prepared than firms from low- and medium low-technology industries.

Table 15: Digital readiness index. Size of firms

	Size*	Lagging Behind	Catching up	Forging Ahead
Argentina	Large (n= 38)	31.6%	55.3%	13.2%
Argentina	Small (n= 133)	69.9%	26.3%	3.8%
Brazil**	Large (n= 197)	37.2%	47.3%	15.5%
Ghana	Large (n= 59)	83.1%	13.6%	3.4%
Ghana	Small (n= 138)	94.2%	5.8%	0.0%
Thailand	Large (n= 105)	76.2%	23.8%	0.0%
Thailand	Small (n= 95)	85.3%	12.6%	2.1%
Viet Nam	Large (n= 157)	63.1%	26.8%	10.2%
Viet Nam	Small (n= 105)	70.5%	26.7%	2.9%

Note: * Large: 100 or more employees; Small: less than 100 employees. **In the Brazilian survey, only firms with more than 100 employees were interviewed.

Source: UNIDO/IE-UFRJ database based on country-level surveys.

In addition, the pattern differs across countries, though there are also some similarities.

- In Argentina and Viet Nam, the percentage of firms among the three groups is similar: around 45 per cent of high- or medium high-technology firms are lagging behind or catching up, while a considerable share of low- and medium low-technology firms are lagging behind (between 75 per cent and 85 per cent of the sample). Differences within the group of firms that is forging ahead are quite substantial: between 7.5 per cent and 11.5 per cent of high- and medium high-technology firms compared to only 3.5 per cent to 4.5 per cent of low- and medium low-technology firms are forging ahead.
- A considerable proportion of firms in Thailand are lagging behind (80 per cent), regardless of sectoral technology intensity.
- In Brazil, most firms are catching up (around 47 per cent); 18.1 per cent of high- and medium high-technology firms and 11.9 per cent of low- and medium low-technology firms are moving forward.

Table 16: Digital readiness index. Sectoral technology intensities of firms

	Sector*	Lagging Behind	Catching up	Forging Ahead
Argentina	H or M-H (n= 80)	45.0%	47.5%	7.5%
Argentina	L or M-L (n= 91)	75.8%	19.8%	4.4%
Brazil	H or M-H (n= 193)	34.7%	47.2%	18.1%
Brazil	L or M-L (n= 135)	40.7%	47.4%	11.9%
Ghana**	L or M-L (n= 197)	90.9%	8.1%	1.0%
Thailand	H or M-H (n= 114)	80.7%	19.3%	0.0%
Thailand	L or M-L (n= 86)	80.2%	17.4%	2.3%
Viet Nam	H or M-H (n= 122)	43.4%	45.1%	11.5%
Viet Nam	L or M-L (n= 140)	85.7%	10.7%	3.6%

Notes: * Sectoral classification based on OECD sectoral technology intensities: H or M-H: High- or Medium High-Technology Industries; L or M-L: Low- and Medium Low-Technology Industries. ** In the Ghanaian survey, only Low- and Medium Low-Technology firms were interviewed

Source: UNIDO/IE-UFRJ database based on country-level surveys.

In summary, firstly, the share of firms that are lagging behind is quite significant in all five countries: around 69 per cent of the entire sample, consisting of one-third of Brazilian firms, around 60 per cent of Argentine and Vietnamese firms, and between 80 per cent and 90 per cent of Thai and Ghanaian firms. At this point, the meaning of "lagging behind" must be elaborated as the majority of firms from the five-country sample lag behind: such firms are currently adopting less advanced DTs, projecting sluggish progress over the next five to ten years and currently investing a minimum of efforts, if any, to meet future expectations. One-third of the five-country sample comprises firms that are catching up and only 7 per cent of the elite firms are forging ahead. Thus, a strong heterogeneity prevails.

Secondly, each country seems to have a specific digital readiness profile and the differences among them are significant. The naval metaphor—ships (Viet Nam and Argentina), submarines (Ghana, Thailand) and naval platforms (Brazil)—illustrates the inter-country diversity.

Thirdly, the structural features of firms shed light on why diversity and heterogeneity exist: the larger and the more technology intensive the industry, the better positioned the firm is to catch up or to forge ahead in terms of its digitalization plans. This, in turn, can be explained by the nature of manufacturing industries in each country, a topic that is beyond the scope of this study. Further considerations on private and public strategic policy will be drawn in the final section of this chapter. Before doing so, the next section explores how DTs affect skill and employment patterns, as well as the extent to which they contribute to energy efficiency and sustainability.

4.4. Implications of digitalization on the nature of skills, levels of employment, energy efficiency and environmental sustainability

In this section, evidence on the implications of advanced DTs on skills, employment, energy and sustainability is analysed based only on the perceptions of firms that are catching up and forging ahead. Firms that are lagging are excluded as a cautionary measure to restrict the analysis to a sub-sample of firms that are effectively moving ahead and mobilizing resources towards their projected futures. As previously explained, firms that are lagging behind are not only trailing behind relative to their peers in adopting DTs at present and in five to ten years from now, but most importantly, they are not engaged in any type of mobilization effort. Thus, the premise of the forthcoming analysis is that projections on the nature of skills, level of employment and impacts of the efficiency derived from advanced DTs by firms that are catching up and forging ahead provide more robust evidence compared to when the laggard group was brought into the analysis.

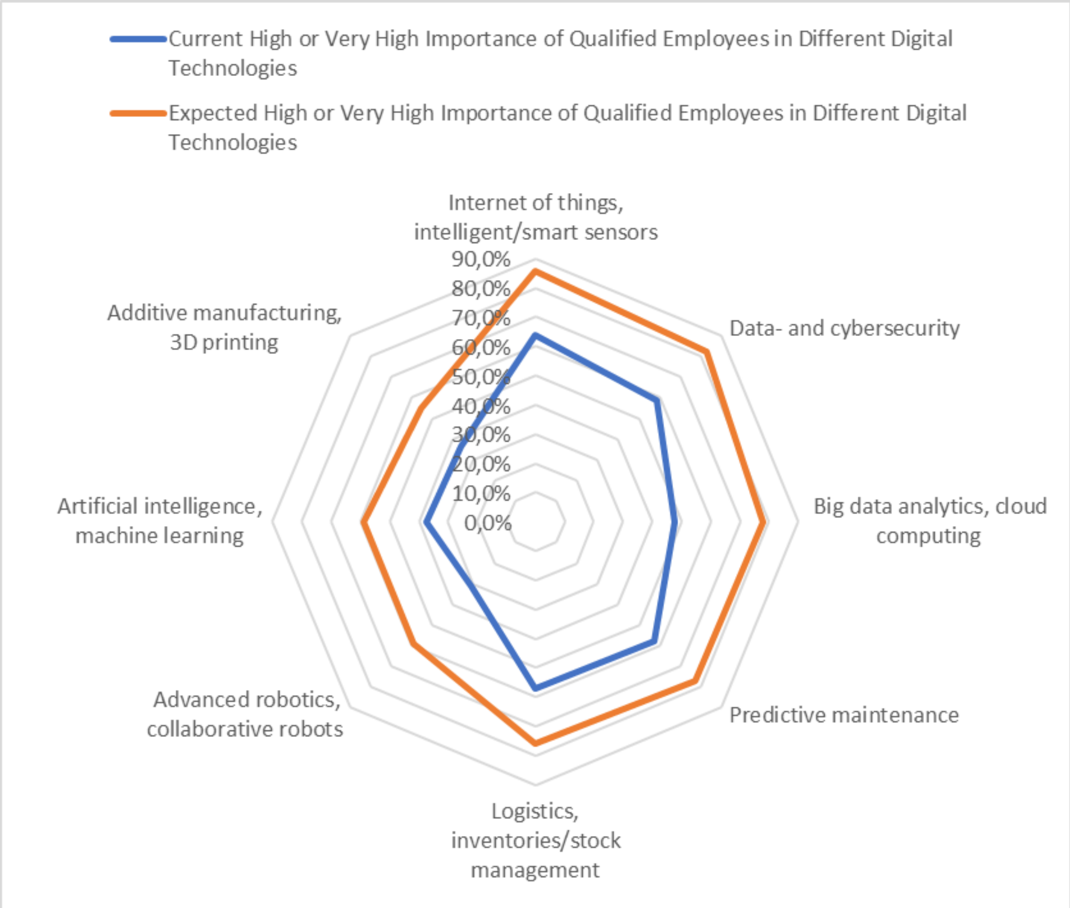
Country, firm size and sectoral technology intensity levels of aggregation are considered. For skills and employment, evidence is derived from Argentina, Ghana, Thailand and Viet Nam; the Brazilian survey did not include questions on these issues. Likewise, evidence on energy and sustainability is only available for Ghana, Thailand and Viet Nam.

4.4.1 Digitalization and skills: towards abstract thinking and intellectualized labour

Figure 4 provides a first piece of evidence on the expectations of firms that are catching up and forging ahead as regards employees' qualifications to operate DTs. When current and future perceptions are compared, the importance of skilled employees to operate all DTs will increase for the majority of firms in the four countries, even if the relative importance among different technologies remains unchanged.

That is, presently and over the next five to ten years, the importance of qualified employees to deal with logistics, the Internet of Things, data security, big data and predictive maintenance is higher than the significance of qualified employees to operate additive manufacturing, machine learning and advanced robotics. Interestingly, the consensus on the degree of importance of the different technologies increases by more or less the same proportion. Thus, an important insight can be gleaned from the relatively high consensus among firms from Argentina, Ghana, Thailand and Viet Nam that are catching up and forging ahead on the relation between qualified workers and advanced DTs: it is more important to have employees qualified in "soft" DTs with a wide scope of application than employees qualified in dedicated, machine-related DTs.

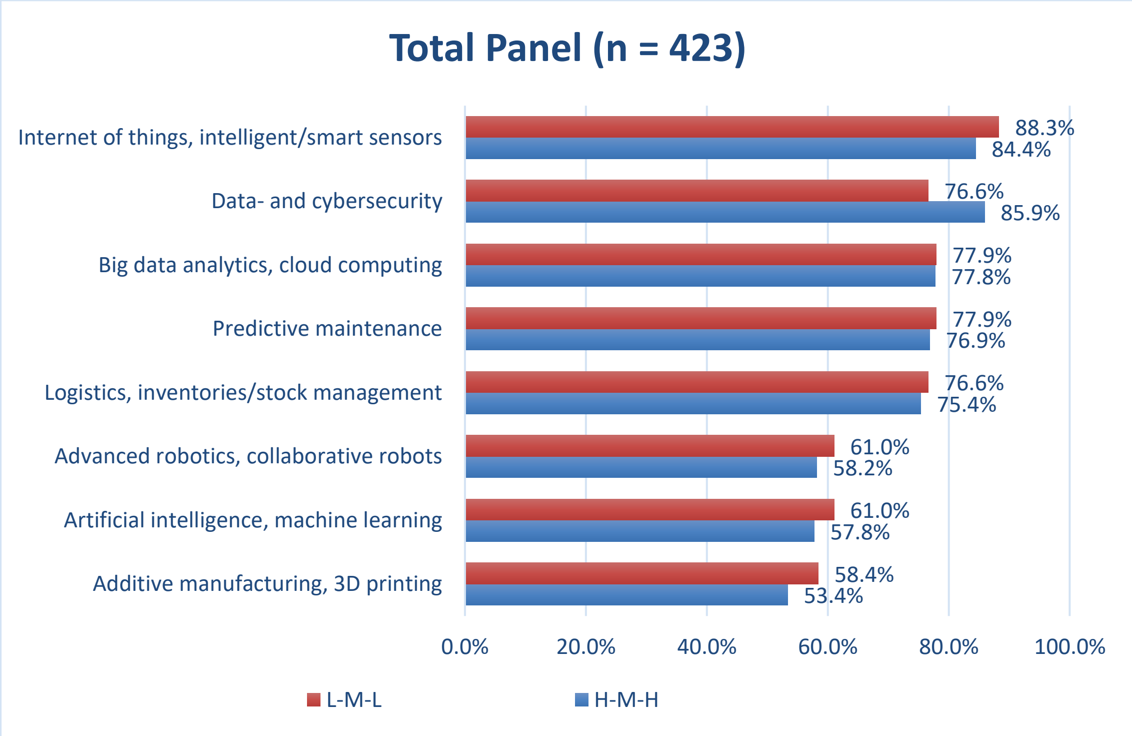
Figure 4: High or very high importance of qualified employees in different digital technologies among catching-up and forging ahead firms, in Argentina, Ghana, Thailand and Viet Nam



Source: UNIDO/IE-UFRJ database based on country-level surveys.

Figure 5 illustrates how L-M-L and H-M-H firms from the four-country sample view the importance of qualified employees to operate DTs. The overall differences between sectoral technology intensities are not significant, the largest difference being 4 per cent for additive manufacturing. Nevertheless, it is noteworthy that consensus among L-M-L firms is higher than among firms from the H-M-H group. The only exception relates to data security: more high- and medium high-technology firms assert that having skilled employees who can operate such technologies is more important compared to low- and medium low-technology firms.

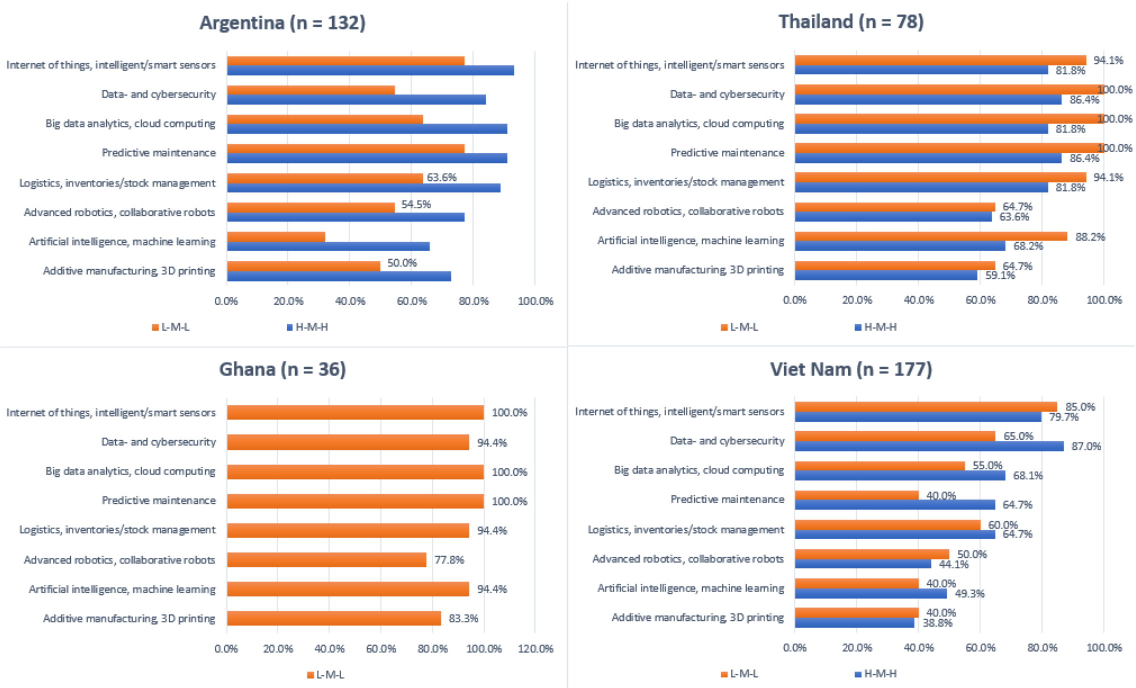
Figure 5: Catching-up and forging ahead firms in Argentina, Ghana, Thailand and Viet Nam by sectoral technology intensities: expected high or very high importance of qualified employees in different digital technologies



Source: UNIDO/IE-UFRJ database based on country-level surveys.

At country level, however, the differences are more pronounced, as Figure 6 illustrates. In Argentina, consensus on the expected significance of qualified labour is more pronounced for all DTs among high-technology firms than among low-technology ones. By contrast, the overall perception in Thailand is exactly the opposite: consensus on the need for qualified workers is higher among low- and medium low-technology firms. In Viet Nam, the results are mixed: more low-technology industries place higher importance on qualified labour working with Internet of Things, robotics and additive manufacturing while for the remaining DTs—big data, cybersecurity, predictive maintenance and artificial intelligence—more consensus on the need for qualified labour is found among high-technology firms. In Ghana, where no high-technology firms took part in the survey, a very high consensus on the importance of qualified labour prevails for all technologies, with the exception of robotics and additive manufacturing.

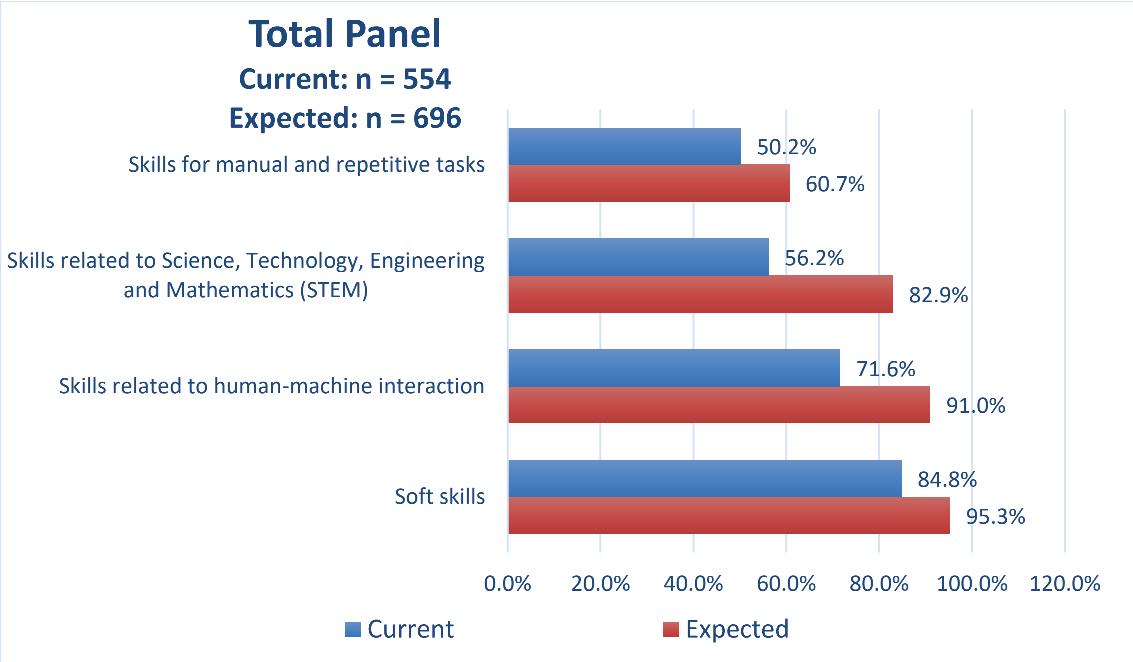
Figure 6: Catching-up and forging ahead firms by sectoral technological intensities and country: expected high or very high importance of qualified employees in different digital technologies



Source: UNIDO/IE-UFRJ database based on country-level surveys.

As regards the nature of skills perceived by the four-country sample firms as being the most relevant to operate DTs, Figure 7 reveals interesting differences between current and prospective perceptions as well as in terms of the relative importance of different skills. The most significant changes are expected in relation to abstract, knowledge-intensive skills, with the four-country sample indicating an increase of around 20 per cent in skills associated with science, technology, engineering and mathematics (STEM) and those related to human-machine interaction. By contrast, between now and the future, the increase in the importance of traditional skills (repetitive tasks and teamwork) is expected to be around ten per cent. These results suggest that firms that are catching up and forging ahead in Argentina, Ghana, Thailand and Viet Nam are expecting a more "intellectualized" skill profile of their labour force in five to ten years. The organizational challenges are significant as hierarchical formats, the delegation of responsibilities, training and sourcing of labour force and even payment structures, among others, may have to change to make an effective and full use of such an emerging skill profile.

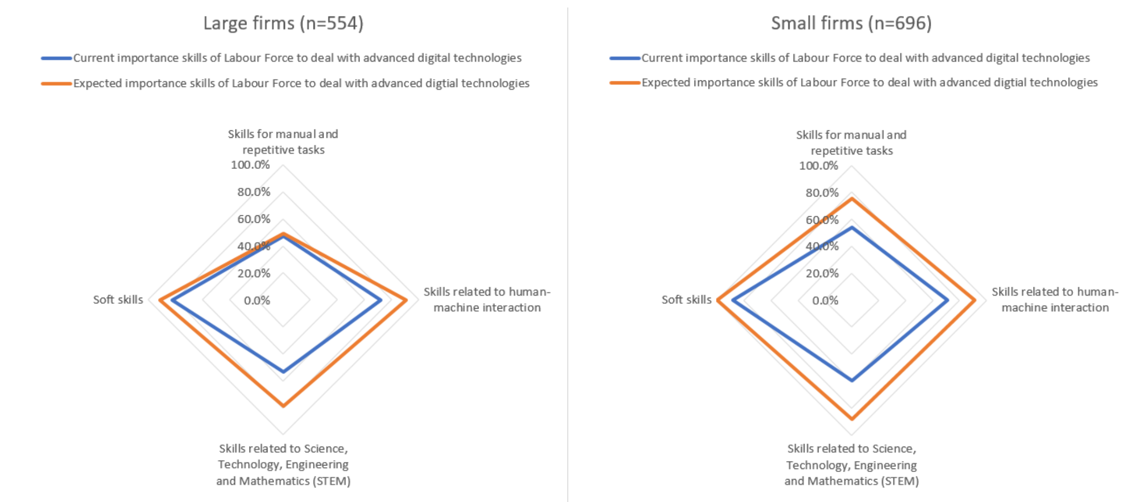
Figure 7: Catching-up and forging ahead firms in Argentina, Ghana, Thailand and Viet Nam. Current and future high and very high importance of specific skills of employees



Source: UNIDO/IE-UFRJ database based on country-level surveys.

Different perceptions according to firm size are also quite interesting. Among large catching-up and forging ahead firms, there is less consensus on the importance of manual tasks, either at present or in five to ten years compared to their small peers (Figure 8). This could be explained by a possible difference in capital/labour ratios between these two types of firms.

Figure 8: Catching-up and forging ahead firms in Argentina, Ghana, Thailand and Viet Nam. Current and future importance of specific skills of employees by firm size

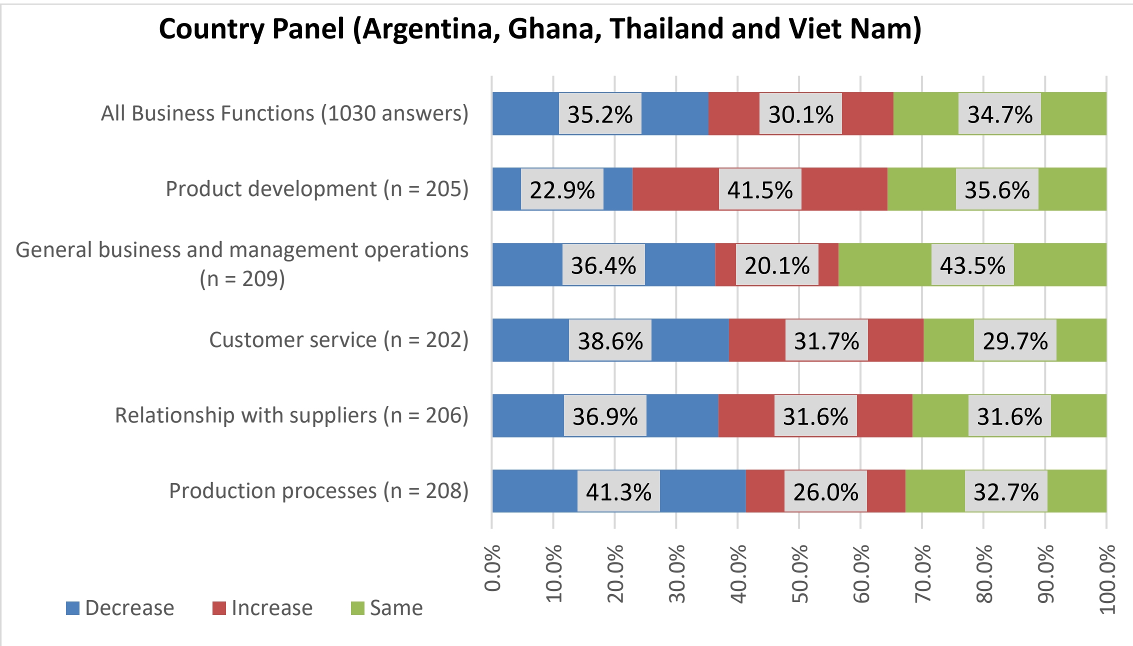


Source: UNIDO/IE-UFRJ database based on country-level surveys.

4.4.1 Digitalization and employment: No consensus on what may happen

Figure 9 illustrates how firms that are catching up and forging ahead from Argentina, Ghana, Thailand and Viet Nam perceive the impact of advanced DTs on the number of employees performing different business functions over the next five to ten years. The sample is divided into three relatively even groups: firms indicating an increase (30.1 per cent), a decrease (35.2 per cent) and no change (34.7 per cent) in the number of employees as a result of the adoption of advanced digital technologies, regardless of business function. Differences in perceptions on the same phenomenon indicate that firms still do not envisage the direction of changes in employment – which is also an intensely debated topic in international forums. Meanwhile, as shown previously, relative consensus on skills emerged in terms of prospective capacity of workplaces. The only noticeable difference arises in relation to product development, where 41.5 per cent of catching-up and forging ahead firms in these four countries expect the number of employees to increase. This could be related to a deepening and widening of the effects of advanced digital technologies on activities related to product development.

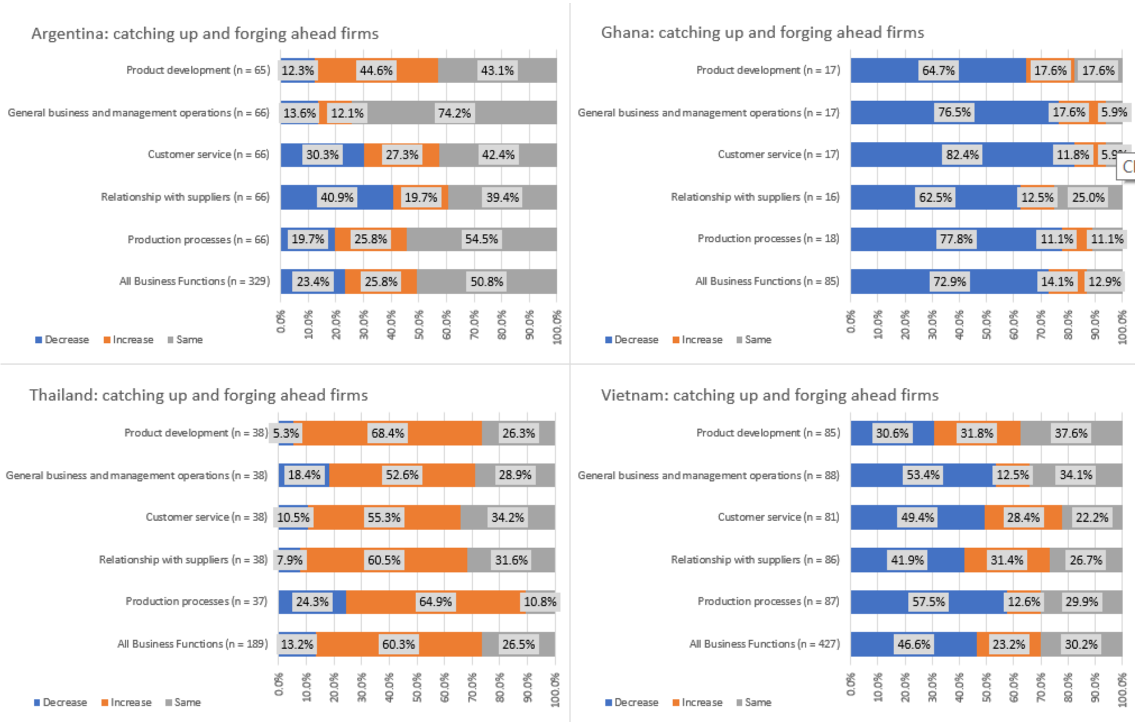
Figure 9: Catching-up and forging ahead firms: likely impact on number of employees in five to ten years due to the expected adoption of digital technologies



Source: UNIDO/IE-UFRJ database based on country-level surveys.

At country level and considering the different business functions, more marked differences become visible (Figure 10). In a schematic description, Argentine firms tend to claim that not much change is expected. The only business function that differs is business management, where 74.2 per cent of firms do not envisage changes in the number of employees in the future as a result of DT adoption. Among Ghanaian firms, there is strong consensus on decreases in employment in all business functions (62.5 per cent in the relationship with suppliers and 82.4 per cent in customer services); a pattern of response also found—albeit less frequently—among Vietnamese firms (30.6per cent in product development and 57.5 per cent in the production process). Meanwhile, consensus among Thai firms runs in exactly the opposite direction, namely towards an increase in all business functions (52.2 per cent in overall business management and 68.4 per cent in product development).

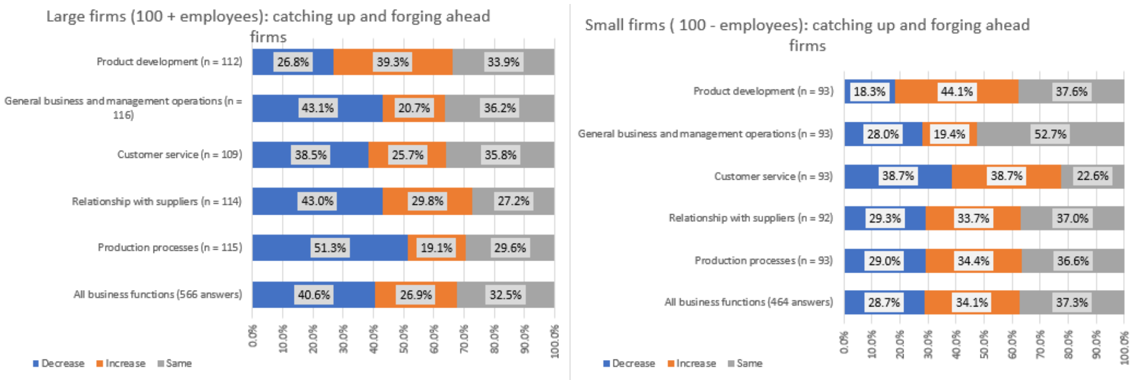
Figure 10: Catching-up and forging ahead firms: likely impact on number of employees in five to ten years due to expected adoption of digital technologies by country



Source: UNIDO/IE-UFRJ database based on country-level surveys.

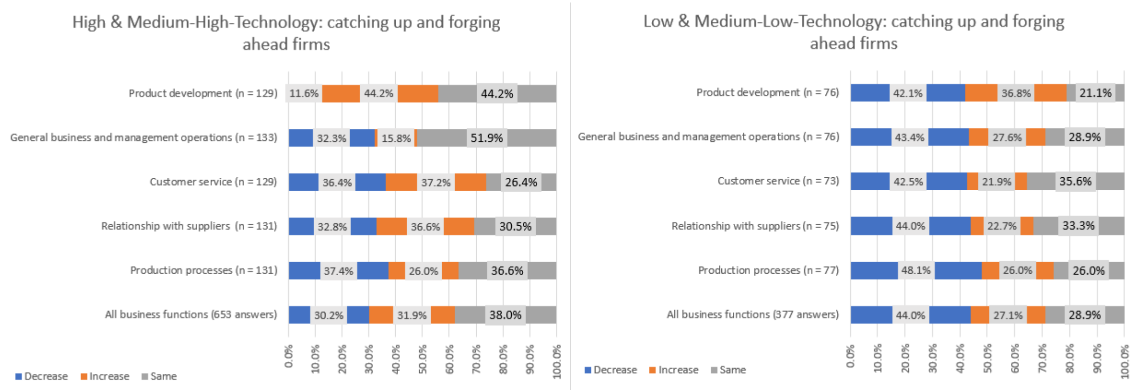
Figures 11 and 12 provide evidence on the perception of firms that are catching up and forging ahead from Argentina, Ghana, Thailand and Viet Nam on the impact of advanced DTs on the number of employees according to firm size and sectoral technology intensity. The non-consensus pattern is revealed once more. Based on size, 30.2 per cent envisage a decrease, 31.9 per cent an increase and 38 per cent see no changes in the number of employees due to the adoption of DTs. The only exception is in relation to business management, for which the majority of firms do not expect any changes in the number of employees. Interestingly though, small firms tend to be slightly more optimistic about an increase in the number of employees than their large peers in almost all business functions. High- and medium high-technology firms are also slightly more optimistic than low- and medium low-technology ones.

Figure 11: Catching-up and forging ahead firms in Argentina, Ghana, Thailand and Viet Nam: likely impact on number of employees in five to ten years due to expected adoption of digital technologies by firm size



Source: UNIDO/IE-UFRJ database based on country-level surveys.

Figure 12: Catching-up and forging ahead firms in Argentina, Ghana, Thailand and Viet Nam: likely impact on number of employees in five to ten years due to expected adoption of digital technologies by sectoral technology intensity of firms

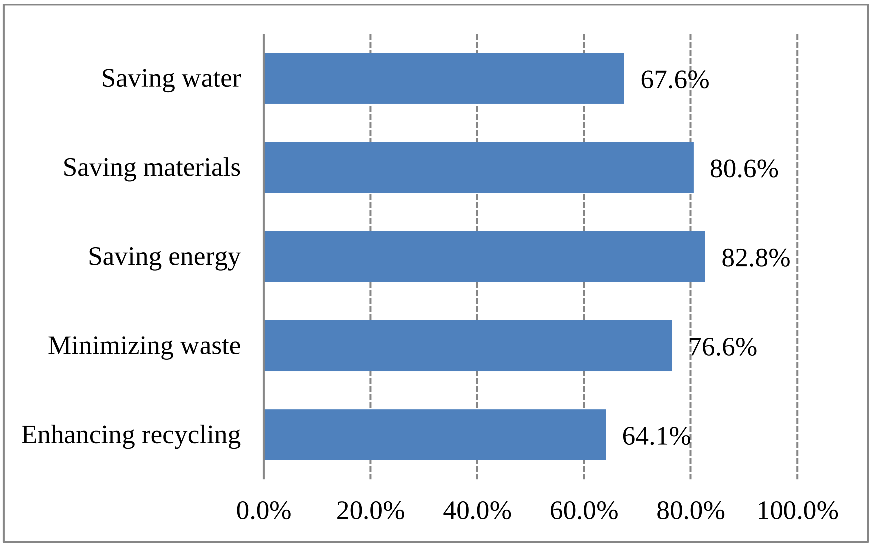


Source: UNIDO/IE-UFRJ database based on country-level surveys.

4.4.2 Digitalization, energy efficiency and environmental sustainability: A positive direct relationship

The final sub-section of this chapter explores how catching-up and forging ahead firms from Ghana, Thailand and Viet Nam perceive the importance of advanced DTs to improve their environmental sustainability. As shown in Figure 13, at least two-thirds of firms from the three-country sample indicate that the contribution of advanced DTs to environmental sustainability is high or very high. This consensus is higher for saving energy (82.8 per cent) and inputs for production (80.6 per cent). As firms from this sample are moving forward in DTs, the pattern of answers indicates a higher sensibility to inputs and energy relative to other environmental issues related to production.

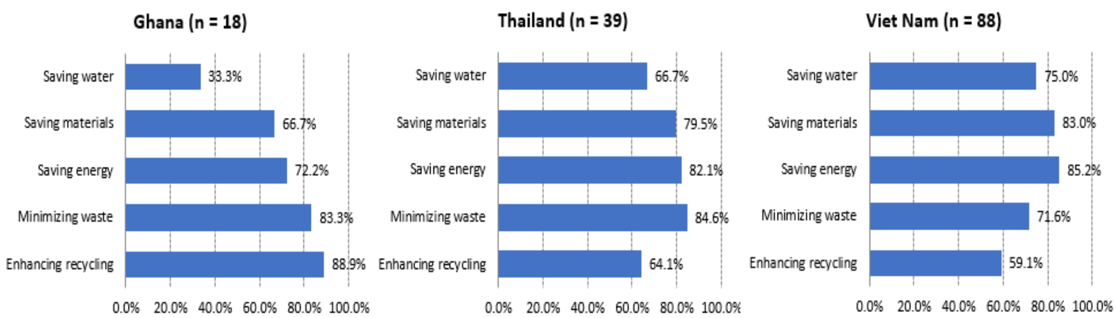
Figure 13: Catching-up and forging ahead firms in Ghana, Thailand and Viet Nam: high and very high contribution of advanced digitalization in five to ten years in improving environmental sustainability



Source: UNIDO/IE-UFRJ database based on country-level surveys.

Where firms place more or less importance in terms of the contribution of DTs to environmental sustainability differs between the countries. As Figure 14 suggests, Ghana is focussed on minimizing waste and enhancing recycling, while Thailand and Viet Nam's catching-up and forging ahead firms believe that DTs can provide a higher contribution to saving inputs and energy.

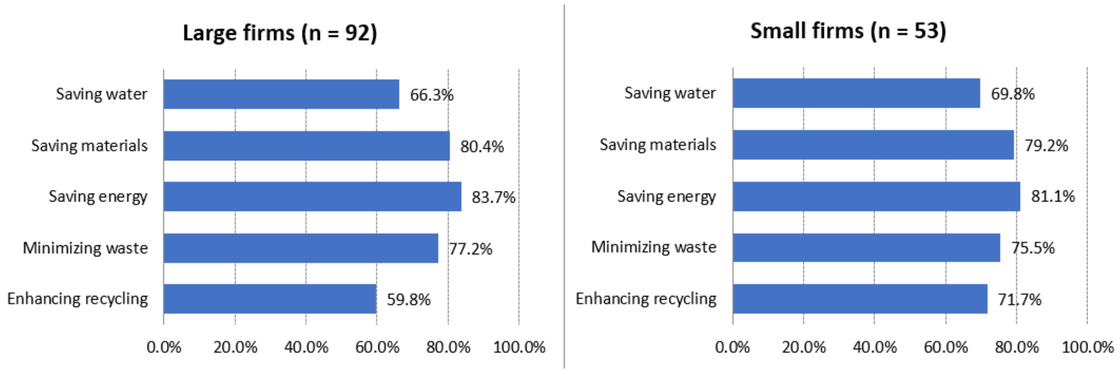
Figure 14: Catching-up and forging ahead firms in Ghana, Thailand and Viet Nam: high and very high contribution of advanced digitalization in five to ten years in improving environmental sustainability by country



Source: UNIDO/IE-UFRJ database based on country-level surveys.

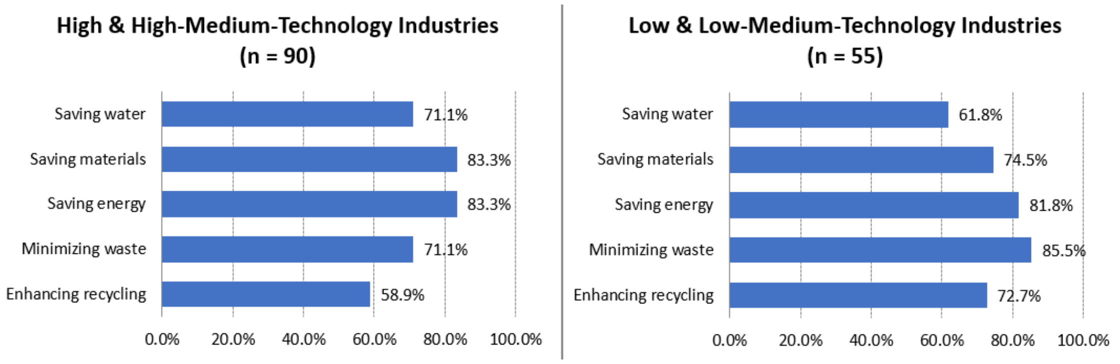
Figures 15 and 16 present evidence of the relationship between DTs and environmental sustainability according to firm size and sectoral technology intensity of catching-up and forging ahead firms. In terms of size, the perception of the contribution of DTs is homogeneous, with one exception: there is higher consensus among small firms compared to their large peers on the importance of DTs for increasing recycling. In terms of sectoral technology intensity, the differences are more pronounced: low- and medium low-technology firms agree more that DTs play an important role in reducing waste (85.1 per cent vs 71.1 per cent for high-technology firms) and increasing recycling (72.7 per cent vs 58.9 per cent), while high- and medium high-technology firms agree more than their low- and medium low-technology peers on the importance of DTs for saving water and materials (71.1 per cent vs 61.8 per cent, and 83.3 per cent vs 74.5 per cent, respectively).

Figure 15: Catching-up and forging ahead firms in Ghana, Thailand and Viet Nam: high and very high contribution of advanced digitalization in five to ten years in improving environmental sustainability by firm size



Source: UNIDO/IE-UFRJ database based on country-level surveys.

Figure 16: Catching-up and forging ahead firms in Ghana, Thailand and Viet Nam: high and very high contribution of advanced digitalization in five to ten years in improving environmental sustainability by sectoral technology intensity of firms



Source: UNIDO/IE-UFRJ database based on country-level surveys.

5. Conclusion: Digital technologies open windows of opportunities for development if related challenges are overcome

The economic relevance of DTs is on the rise. As digital technologies evolve, information can flow in real-time among different departments of firms and their suppliers, service providers and customers. As a result, firms may become more integrated, interconnected and intelligent. If effectively managed, digital solutions can lead to lower transaction costs, including time to market, from R&D to the final client. DTs also provide firms with process and product flexibility based on simulations of processes and demand possibilities, allowing for virtual testing of alternatives for success.

But, the introduction of DTs in organizations is a complex process, associated with at least four different types of challenges.

Firstly, the more complex a digital solution is, the more complex the capability requirements are for it to be effective. Even simple digital solutions require changes in analogous competences and, when introduced at specific sites, context-based and explicit learning efforts are necessary.

Secondly, benefits from digitalization can be accrued in the short term, but even more so in the long run. Specific solutions applied to specific problems—such as digital measurement and control devices for energy or water consumption, for example—may affect the efficiency or quality levels in the short run. By contrast, either through cumulative and localized improvements or via the introduction of an integrated solution (the overhaul of an enterprise resource planning system), DT investments open spaces for new opportunities that may lead to changes in business models. DT solutions can thus be viewed as triggers of structural change at firm, competitive and sectoral levels.

Thirdly, the cost/benefit equation of investments in DTs is not a simple assessment because of the cumulative nature of investments in such solutions and continuous technical progress. The only guaranteed requirement is that the effective introduction of DTs in organizations requires efforts and capabilities at a level of sophistication required to adopt the intended solution.

Finally, the nature of "capabilities" requiring investment is very new to many firms, especially in developing countries. The skill profile of the labour force of firms that are forging ahead and catching up will be increasingly "intellectualized" in the sense that abstract thinking will become more relevant compared to practical experiences. The organizational consequence for firms moving forward with their plans to adopt more advanced digital solutions over the next five to ten years is quite significant: a different type of organization in terms of hierarchical formats, delegation of responsibilities, training and sourcing of the labour force and even payment structures, among others, must emerge to make profitable use of DTs. In this reality, where specific strengths and weakness of firm capabilities matter, markets have limited resources to provide and sustain adequate solutions; as decision-makers have knowledge of the idiosyncrasies of their firms and have comprehensive insights into targets that ought to be pursued and which internal mobilization efforts are of strategic importance to trigger processes of change. In short, there is no substitute for well-versed decision-makers for the task of defining challenges to address, allocation of resources and the monitoring of consequences of investments in DT solutions.

Consequently, one major task for decision-makers in any organization is how to implement the level of capabilities required for the level of DT generation they aim to achieve. Although a supply market and sufficient benchmark references exist for the majority of DTs, a "store-bought solution" will not be a proprietary innovation such as the results of R&D efforts might be. Entrepreneurs will have the challenging task of searching for and opening the new windows of opportunities advanced digital solutions offer. These solutions must be firm-specific, take account of the fact that technologies are constantly evolving and that capabilities must, at the same time, be adapted to the progress being made. Policy support can be put forward by providing information for private sector decision-making and once decisions are taken up, public agencies—and the supplier private sector—should take action to provide the adequate and necessary support required by firms.

This paper has provided evidence for a sample of 1,158 industrial firms from five countries—Argentina, Brazil, Ghana, Thailand and Viet Nam—about the current and prospective adoption of different generations of DTs, and their mobilization efforts to achieve intended future levels of DT. The main hypothesis put to test was whether different generations of DTs coexist among firms which would reveal particular structural features of developing countries – diversity and heterogeneity.

These two structural features of developing countries, highlighted in the literature review of section 2, were evidenced in the results obtained when size and sectoral technology intensity of firms were compared and even more so when current and expected digitalization were associated with firms' mobilization efforts to achieve their projected future (Digital Readiness Index). The evidence is very clear: currently, very basic generations of DTs prevail in Argentina, Brazil, Ghana, Thailand and Viet Nam; the future expectations are that major developments will take place, but the Digitalization Readiness Index suggests that firms are for the most part not well prepared to achieve their projected progressive future.

At country level, the nature of diversity and heterogeneity related to the current and prospective adoption of DTs by the five-country sample is represented by means of the naval vessel metaphor. Ghana and Thailand have a very large share of firms that are lagging behind (between 80 per cent and 90 per cent), a small group of catching-up firms (between 10 per cent and 20 per cent), and a very small share of elite firms (less than 1 per cent of both countries' sample) are forging ahead. This "submarine profile" suggests a relatively high inertia in these countries to move forward, as they lack a flourishing digital ecosystem to facilitate the adoption by firms of more advanced technologies. At the other extreme lies the Brazilian "naval platform profile". This profile is believed to be more conducive to progress, as the middle portion, formed by catching-up firms (47.3 per cent of the Brazilian sample), may serve as the foundation for progress, as well as a significant show case for firms lagging behind. The "ship profile" of Argentina and Thailand is likely a traditional three-layer economic or even social structure: a large base of firms that are lagging behind, a significant middle portion of catching-up firms and a smaller group of firms at the top. Whether positive inducement effects from top to bottom will occur in the years to come remains an open and unpredictable possibility.

At the most disaggregated level, one may argue that large firms in high- and medium high-technology industries are better positioned to introduce DTs compared to their small and lower technology intensity peers. Such findings come as no surprise as it is a common wisdom that such firms are better positioned to advance. This five-country sample of 1,158 firms provide hard evidence for this common wisdom, thus allowing for reflections on the implications for public and private policies.

Such foreseeable results can be explained by the fact that large and high- and medium high-technology firms have more access to information and resources to mobilize and modernize. If the adoption of DTs has competitive implications once such a trajectory is confirmed, changes in market structures may occur towards higher concentrations relative to the current level.

Nevertheless, each country presents a specific pattern of adoption and development towards the future, but it is beyond the scope of the present study to investigate the reasons behind such differences. At this stage, the only preliminary implications for policy design that can be drawn from this research is that private and public policymakers must pay attention to and monitor the patterns of adoption of DTs in industrial firms very closely. This is essential because the specification of measures must be embedded in the local setting to increase the chances of greater effectiveness.

The challenges for the projected future are quite substantial, as the shift from a G1/G2 dominated reality to a G3/G4 projected scenario is not a simple and linear process. As mentioned earlier, significant organizational changes are necessary to integrate business functions, implying a comprehensive and effective standardization of processes and information systems. Challenges surrounding the most advanced generation of DTs are even more pronounced as an extremely high level of internal competences is required to effectively use and exploit the full potential of advanced communication devices, big data and artificial intelligence, among others.

These country-level results have other crucial strategic implications: firms from developed countries have more information capability, resources and policy support to move forward; the best known are the German Industrie 4.0 and the Made in China 25 programmes, but the Republic of Korea, India, France, the UK, Australia, Japan, among others, also have plans in motion. If the firms in these countries move ahead and if the five countries included in this study meet their expectations, there is a high probability that the current international divide in terms of technology and innovation will be further emphasized.

References

Abramovitz, M. (1986) Catching Up, Forging Ahead, and Falling Behind. *The Journal of Economic History*, Vol. 46, No. 2, The Tasks of Economic History (June, 1986), pp. 385-406.

ACCENTURE. (2017) *Industry X.0*: Combine and Conquer - unlocking the power of digital. Available at: <www.accenture.com/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Dualpub_26/Accenture-Industry-XO-whitepaper.pdf>.Accessed on 13 Aug. 2019.

Acemoglu, D. (2002) Technical Change, Inequality, and The Labor Market. *Journal of Economic Literature*, 40, March 2002: pp. 7-72.

Albrieu, R.; basco, A.I; lópez, C.B; azevedo, B.; peirano, F.; rapetti, M.; vienni, G.; (2019B) *Travesia 4.0: hacia la transformación industrial argentina*. Nota Técnica no. IDB-TN-1672, Intal-BID, Buenos Aires

Albrieu, R.; lopez, C.B.; rapetti, M.; ferraz, J.C.; britto, J.N.P.; kupfer, D.; torracca, J. (2019A) *The adoption of digital technologies in developing countries*: Insights from firm-level surveys in Brazil and Argentina. Background Paper for the IDR 2020. Vienna, Austria: United Nations Industrial Development Organization (UNIDO).

Andreoni, A. (2017) Industrial ecosystems and policy for innovative industrial renewal: A new framework and emerging trends in Europe. Available at: <https://tem.fi/documents/1410877/4430406/Antonio_Andreoni.pdf/8a499465-50e2-4bcb-959b-59c5202663f7/Antonio_Andreoni.pdf.pdf> Accessed on 13 Aug. 2019.

Cantner, U.; vannuccini, S. (2012) A New View of General-Purpose Technologies. *Jena Economic Research Papers*, Friedrich-Schiller-University Jena, No 2012-054. Available at: <https://econpapers.repec.org/scripts/redir.pf?u=http%3A%2F%2Fpubdb.wiwi.uni-jena.de%2Fpdf%2Fwp_2012_054.pdf;h=repec:jrp:jrpwrp:2012-054> Accessed on 13 Aug. 2019.

Deloitte (2017). Soft skills for business success. Deloitte Access Economics, May 2017. Available at: <https://www2.deloitte.com/content/dam/Deloitte/au/Documents/Economics/deloitte-au-economics-deakin-soft-skills-business-success-170517.pdf>. Accessed: 19 Apr. 2018.

Deloitte. (2018) *The Fourth Industrial Revolution is here*—are you ready? Deloitte Insights. Available at: <www2.deloitte.com/content/dam/Deloitte/tr/Documents/manufacturing/Industry4-0_Are-you-ready_Report.pdf> Accessed on 13 Aug. 2019.

Ferraz, J.C.; kupfer, D.; torracca, J. Britto, J.N.P: Snapshots of a state of flux: how Brazilian industrial firms differ in the adoption of digital technologies and policy implications. *Journal of Economic Policy Reform*, DOI: 10.1080/17487870.2019.1578651

Gambardella; Torrisi, S. (1998). Does technological convergence imply convergence in markets? Evidence from the electronics industry. *Research Policy*, 27, pp. 445-463.

Geissbauer, R.; vedso, J.; schrauf, S. *Industry 4.0*: building the digital enterprise. London: PwC,

2016. Available at: < https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf>. Accessed on 13 Aug. 2019.

IEL/CNI et al (2018). *Industry 2027: risks and opportunities for Brazil in the face of disruptive innovations. Final report: Building the Future of Brazilian Industry*. Brasília, IEL/NC.

Kagermann, H.; wahlster, W.; helbig, J. (2013) *Recommendations for implementing the strategic initiative Industrie 4.0*. Final Report, Acatech. Available at: <http://www.acatech.de/de/publikationen/stellungnahmen/kooperationen/detail/artikel/recommendations-for-implementing-the-strategic-initiative-industrie-40-final-report-of-the-industr.html>. Accessed on 13 Aug. 2019.

KMPG. (2016) *The disruptors are the disrupted. Disruptive technologies barometer*: Technology sector. KPMG International. Available at: < https://assets.kpmg/content/dam/kpmg/xx/pdf/2016/11/disruptive-technologies-barometer-tech-report.pdf>. Accessed on 13 Aug. 2019.

Levy, F.; murnane, R. (2013) Dancing with robots: human skills for computerized work. Third Way Think Tank, June 2013. Available at: <http://content.thirdway.org/publications/714/Dancing-With-Robots.pdf>. Accessed 18 Apr. 2018.

Mckinsey Global Institute. (2017) *A future that works*: automation, employment, and productivity Mckinsey and Company, January. Available at: <https://www.mckinsey.com/~/media/mckinsey/featured%20insights/Digital%20Disruption/Harnessing%20automation%20for%20a%20future%20that%20works/MGI-A-future-that-works-Executive-summary.ashx>. Accessed on 13 Aug. 2019.

Mokyr, J.; vickers, C.; ziebarth, N. L. (2015) The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different? *Journal of Economic Perspectives*, Vol. 29, No. 3, Summer, pp. 31-50. Available at: < https://www.aeaweb.org/articles?id=10.1257/jep.29.3.31>. Accessed on 13 Aug. 2019.

OECD – ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (2017). *The next production revolution*: implications for governments and business. Paris: OECD Publishing, 2017.

Pounder, K.; Liu, G. (2018) New Jobs. *Integration and Trade Journal*, Vol., No. 44, July, pp. 255–270. Available at: <https://publications.iadb.org/handle/11319/9080>. Accessed on 13 Aug. 2019.

Rifkin, J. (2015) *The Zero Marginal Cost Society*: the internet of things, the collaborative commons, and the eclipse of capitalism. New York, Palgrave Macmillan, 2014.

Rosenberg, N. (1963). Technological Change in the Machine Tool Industry, 1840-1910. *The Journal of Economic History*, 23, 414-443.

Wilson, H. J.; Daugherty, P. R. (2018) Collaborative Intelligence: Humans and AI Are Joining Forces. *Harvard Business Review*, July – August Issue. Available at: < https://hbr.org/2018/07/collaborative-intelligence-humans-and-ai-are-joining-forces>.

Accessed on 13 Aug. 2019.

World Bank Group (2016). *World Development Report 2016*: Digital Dividends. The World Bank. Available at: < https://www.worldbank.org/en/publication/wdr2016>. Accessed on 13 Aug. 2019.

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Vienna International Centre · P.O. Box 300 9 · 1400 Vienna · Austria
Tel.: (+43-1) 26026-0 · E-mail: info@unido.org
www.unido.org