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ARTICLE
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Digital heterogeneities in developing countries: a comparative analysis

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ABSTRACT

This article investigates patterns of digital technologies' adoption by industrial firms of selected developing countries, namely: Argentina, Brazil, Ghana, Thailand, and Vietnam. The objective is to identify inter and intra countries' similarities and differences in terms of digital adoption, and understand how this distribution is leading to digital heterogeneities thus reinforcing the well-entrenched structural heterogeneity prevailing in these economies. The analysis is based on surveys carried out between 2017 and 2019 that covered a panel of 1,212 firms of varied sizes and industries. The evidence shows that most firms are currently adopting a low level of digitalization and have a positive expectation for the future even with a low level of readiness. The larger and technology intensive firms are, the higher the probability of firms being digitally progressive. These results suggest an increase of inter and intra countries' asymmetries in digital adoption, bringing the emergence of digital heterogeneities.

KEYWORDS | Technology adoption; Digitalization; Industrial firms; Developing countries; Heterogeneity

1. Introduction

Digital-based technologies (DBT) when effectively adopted by industrial firms may contribute to enhance production efficiency, lower transaction costs, increase control over production processes, higher levels of safety, more differentiated and better product quality thus leading firms to increase their competitive capacity and create closer relations along value chains (UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION, 2019). Theoretically, DBT could enable countries to bypass or lower well-entrenched development hurdles, permitting them to enter or expand their manufacturing capabilities through efficient production processes and thus generate competitive, newer, and affordable products (STEIBER et al., 2020). As some of these technologies are less scale-demanding, they may also open the ways and new opportunities for small-scale producers. At the same time, technologies can also transform the provision of essential services such as health and education, permitting to cope with some of the most existential problems of development. But the debate over whether and how DBT can contribute to sustainable development and or structural change is far from over.

Firstly, the process of technology generation of digital devices remains concentrated in a few economies (UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION, 2019). Specifically, about ten countries are responsible for above 90% of all global patent applications in this technological field and almost 70% of the exports of digital-related capital goods. Few developing countries have taken initial steps to engage in the production, or at least the assembly, of new technologies, but it is not yet clear whether they will succeed in going upwards the development ladder. But, from a technology adoption perspective, different views may arise. According to Matthess and Kunkel (2020), digital adoption by firms may accelerate structural changes inherent to catching-up processes through three drivers: (1) altering relative sectoral productivity and labor movements; (2) inducing changes in the skill profile of the labor force, which may lead to more equitable income gains, and induce inter-firm linkages; (3) promoting

the servicification of manufacturing, leading to the diversification of product portfolio of firms towards the provision of services and trade.

However, many controversies remain about whether industrial digitalization really facilitates the progress of developing countries and their better positioning in international markets, or if it narrows the scope for internal manufacturing and their participation in local and global value chains. Also, the wide diffusion of DBT by industrial firms in developed countries may reduce the cost competitiveness of less industrialized economies, increasing technological gaps and making harder processes of catch up, the diversification of developing economies and their capacity to generate new jobs, thus placing them in a stranded development (UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT, 2021).

Secondly, given their potentially disruptive character, DBT may create unique opportunities for latecomers (firms or countries) to catch up with their more advanced peers, especially those that are proactive and quick learners. Even if some DBT require high intensity in capital utilization, a restriction for many developing countries, some digital devices and solutions, in specific activities, may not require high skill levels and capital investment, permitting effective entry into digitalization at low cost. Leapfrogging processes thus could be facilitated. However, according to Schlogl (2020), the infant stage of development and/or ongoing processes of deindustrialization in many emerging countries impose at least three development hurdles: 1) a process of hybridization or polarization of sectors in the process of industrial upgrading; 2) contradictory processes of upskilling in the labor market, together with an increase in redundancies due to the impact of automation; 3) offshoring and 'reshoring' of economic activities, changing established patterns of global trade in which developing countries were active participants of value chains even if in a subsidiary role.

The challenge of absorption and deployment of DBT in industrial firms of developing countries is to integrate them in order to execute production tasks within existing production systems which, in turn, requires retrofitting and the development of new capabilities to run them effectively (ANDREONI; ANZOLIN, 2019). In this sense,

effectiveness in the use of DBT should be strongly correlated with the capacity of firms to engage and mobilize information, skills and devices appropriate to their stage of development and needs.

In a polarization stylization, in one extreme the lower the capabilities and factor endowments of firms, the harder the adoption of digital devices would be, even those technically simple. In the other extreme, firms closer to the productive frontier would have the appropriate assets to effectively choose and adopt digital devices appropriate to their needs, even those technically complex. Naturally such polarization is an oversimplification of the economic reality of any developing nation.

The main argument of this article though is that digital heterogeneity, comprehended as the co-existence of asymmetric adoption patterns of digital technologies among and within countries, is the main feature of developing countries just as the co-existence of low-capability and low-performance firms and sectors with more advanced ones conforms the scenario of structural heterogeneity of development processes (ECONOMIC COMMISSION FOR LATIN AMERICA AND THE CARIBBEAN, 2021).

For the empirical evaluation of the process of adoption of DBT, reliable databases and indicators at the firm level, especially in developing countries, are scarce and confined to a few technologies and sectors (CIRERA et al., 2021). This article explores a unique database of the current and projected adoption of different generations of digital solutions in five business functions – relations with suppliers, production management, product development, relations with clients and business management – covering 5 countries, Argentina, Brazil, Ghana, Thailand and Vietnam[1], through direct surveys undertaken between 2017 and 2019 focusing on manufacturing firms. From these surveys a comparable panel of 1,212 firms was organized and appropriate

[1] The mode of questioning firms about digital adoption was similar in the different surveys even if the five countries were not chosen based on any pre-defined parameter. Topical opportunities arose while surveys were carried out. Such diversity of countries´ history, size, location and recent history makes this analysis at least very instigating.

indicators were developed to allow the enquiring of the following questions[2]: (i) How advanced is the process of digital adoption in these countries? (ii) Does size and sector of origin explain differences in the observable patterns of digital adoption? (iii) At the level of countries, how is the distribution of the distance between more and less advanced technology adopters? Is the adoption pattern similar?

The structure of the paper will be as follows. Section 2 will provide an overview of the debate about digitalization in developing countries with a special attention to possible asymmetries in the process of digital adoption. Section 3 will provide an economic overview of the 5 countries to familiarize the reader with each one' main features and their similarities and differences. Section 4 describes the methodological procedures of the empirical surveys and which procedures were used in the design and build up of a comparable database for the five countries. Section 5 is dedicated to the comparative analysis of the digital adoption of the countries, discussing their current and expected adoption of digital technologies, as well as the nature of actions currently taken by surveyed firms to achieve the projected future. The final section will discuss the main findings regarding their digital heterogeneity.

2. Digitalization in developing countries

The adoption of digital technologies is, in essence, an asymmetric process among firms. The conceptual model of digital adoption works mainly at the organizational level as well as between the firm and societal level factors (DOE et al., 2017). Firm-level factors lead to the adoption of digital technologies based on a set of features, like the expectative of returns on investments, organizational readiness, and managerial innovativeness (BOATENG et al., 2011); strategic fit

[2] This panel is not representative, in the statistical sense, of the industrial reality of each country. However, it is hoped that this article reveals patterns and suggests trends that may be useful for the academic, strategic and policy debates and pave the way for further systematic conceptual, methodological and empirical exercises.

(D'AMBRA; WILSON; AKTER, 2013); and industry readiness issues (ROGERS, 1983). In addition, technological adoption is also linked to existing capabilities, accumulated learning, to the alignment of behavioral variables and expectations to improve production efficiency, which is also quite diverse among firms. In aggregated terms, this implies a minimum of common industrial capacity, at least in terms of homogeneity of firms' capabilities, that must be built for industry-wide diffusion processes to succeed (BOGLIACINO; CODAGNONE, 2019). Otherwise, the adoption of new technologies such as DBT tends to be slow and highly asymmetrical.

Empirical studies associate heterogeneous processes of technology adoption to the characteristics of firms, such as the skill composition of the workforce and their organizational structure as driving factors behind differentials in returns derived from using new technologies (DAVID, 1969; DAVIES, 1979). Also, larger, younger, fast-growing, skill-intensive, export-intensive and firms located in the urban regions have shown to be relatively more successful in adopting and using digital technologies (HALLER; SIEDSCHLAG, 2011). The returns from adopting new technologies also depend, to some extent, on a firm´s position in the order of adoption: early adopters achieve a greater return than late adopters (FUDENBERG; TIROLE, 1985).

Taking into account the reality of developing countries, other issues emerge. Digital transformation in these cases faces other constraints such as the presence and seizure of informal sectors and the lack of diversification of the economic structure (BOGLIACINO; CODAGNONE, 2019). In this respect, part of the heterogeneity problem arises from the fact that the knowledge economy is still confined to islands of vanguards within each sector (UNGER, 2019). Surrounding these digital advanced islands, a large contingent of companies would be fully operating with old technology paradigms, thus unable to operate as the same standards of their counterparts (ANDREONI; ANZOLIN, 2019).

Differences in the rate and nature of technology adoption are an important determinant of the widening productivity gap between leader and laggard firms in developing countries (CIRERA et al.,

2021). For Brixner et al. (2020), Latin American countries show great differentials regarding the adoption of new technologies as being a new source of structural heterogeneity. For the authors, severe difficulties in appropriating the productivity gains and quasi-rents exist and these can be explained, partially, by the weak technological, organizational, and connectivity capabilities paths of accumulation between institutions and actors.

The discussion on the differences in technology adoption and their possible impacts in terms of structural heterogeneity suggests a relevant research agenda: first, in how to detect technology adoption levels and, second, in how to identify features of advanced and non-advanced firms. Moreover, the developing countries' context brings another analytical dimension and challenge: the potential wide differences – heterogeneity – in the adoption of new technologies among firms. Inter-firm and intra-firm heterogeneity in the adoption of DBT requires measures of variance in the intensity of adoption of new technologies among local firms. In this case, and this is the direction taken in this article, the variability between levels of adoption of digital technologies between firms and countries – reflected in the variance of the measures used to capture the process of digital adoption – would reveal important clues about the scope of digitalization processes in developing countries.

Before taking the methodological step to define how to go about in the analysis of variance in digital adoption, it is useful to signalize the main economic features of the five countries under consideration in order to characterize the structural issues that could restrict in some sense their digital infrastructure.

3. Economic features of Argentina, Brazil, Ghana, Thailand and Vietnam

From the classification proposed by World Bank (2021), the five surveyed countries can be classified into different categories in terms of GDP per capita. Argentina, Brazil, and Thailand are considered

upper-middle-income level countries, while Ghana and Vietnam are in the lower middle-income bracket. Table 1 provides the GDP and GDP per capita average annual growth for the 2000-2020 period. It shows that Vietnam, followed by Ghana and Thailand revealed an evolution with values significantly higher than the world average, in contrast to what was observed in the case of Brazil and Argentina.

TABLE 1
Economic Indicators of the surveyed countries: 2000-2020

	World	ARG	BRA	GHA	THA	VIET
GDP growth (annual %) - Mean 2000-2020	2.6	1.4	2.1	5.8	3.5	6.3
GDP per capita growth (annual %) - Mean 2000-2020	1.4	0.4	1.1	3.3	2.9	5.3
Gross fixed capital formation (% of GDP) - Mean 2000-2019	23.6	15.9	18.0	21.8	24.4	28.5
Trade (% of GDP) - Mean 2000-2019	56.4	33.0	25.9	82.0	126.4	155.0

Note: ARG = Argentina; BRA = Brazil; GHA = Ghana; THA = Thailand; and VIET = Vietnam.
Source: Own elaboration based on World Development Indicators (WDI) Database - World Bank

On the same line, investments, as measured by the average annual rate of Gross Fixed Capital Formation in relation to GDP between 2000-2019, present higher values than the world average only for Vietnam and Thailand. This is an important measure as it signals the construction of conditions that allows for catching up and the creation of productive capacity. Concerning the degree of trade openness, measured by the participation of foreign trade in relation to GDP, Table 1 shows a relatively greater trade opening in Vietnam and Thailand compared to Brazil and Argentina, while Ghana is placed in an intermediate position.

Differences among countries can also be appreciated from the inequality perspective. From the World Development Indicator assembled by the World Bank, in 2016[3] the income share held by the

[3] The most recent information available for the five countries is for the year 2016.

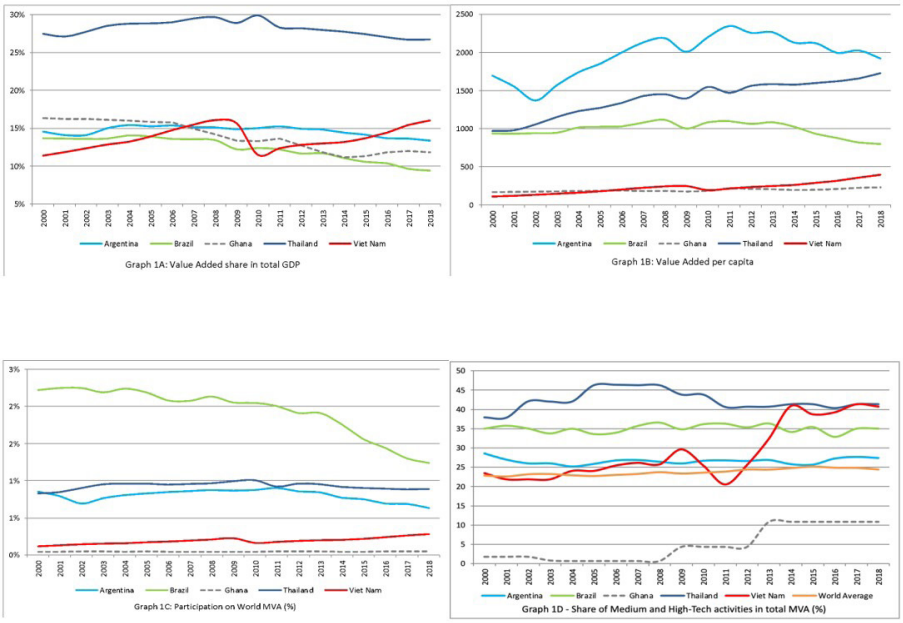
highest 10% of the population was 30.4% for Argentina, 42.0% for Brazil, 32.2% for Ghana, 28.9% for Thailand and 27.1% in the case of Vietnam. Such wealth parameter gives evidence that, to a great extent, the five countries have a relatively high degree of social inequality. This indicator provides a glimpse into an important facet of the heterogeneity within these countries, which could somehow reverberate and be also present in other dimensions of their state of development.

In terms of their productive structure, it is important to reveal the evolution of the manufacturing industry as it is associated in some sense with the capacity to create and absorb new technologies. On average, the share of the manufacturing sector in relation to GDP for the period 2000-2018 was higher in Thailand (around 28%) in comparison to the rest of the countries, whose shares are around 13%-14% (Graph 1A). Except for Vietnam, such indicator evolves negatively in all countries, with a more pronounced fall in Brazil. The level of Manufacturing Value Added per capita was higher for Argentina, followed by Thailand and Brazil (Graph 1B). About the impact of a country on world manufacturing value added (Graph 1C), Brazil stands out for the largest share (1.94%), despite an annual average drop of 3.1% over the period. Thailand observes an average share of 0.93% followed by Argentina (0.8%), Vietnam (0.19%) and Ghana (0.05%)

Concerning the participation of medium and high technology sectors in the total value added of manufacturing, Thailand shows the highest share on an average between 2000-2018 (42.2%), followed by Brazil (35.1%) and Argentina (26.6%) (Graph 1D). Vietnam had an average of 28.9% during the period considered, but since 2011, due to their engagement in regional value chains, the country significantly improved its trade share of these goods. Except for Ghana, all countries have a higher proportion than the world average (around 23%), however well below the average observed by the five[4] main countries in the world that was around 65%. The evolution of this indicator shows some stability in Argentina and Brazil, a small growth in the case of Thailand and a more expressive growth in the case of Vietnam. Such

[4] United States, China, Japan, Germany, and United Kingdom.

GRAPH 1
Indicators of manufacturing industry (2000-2018)

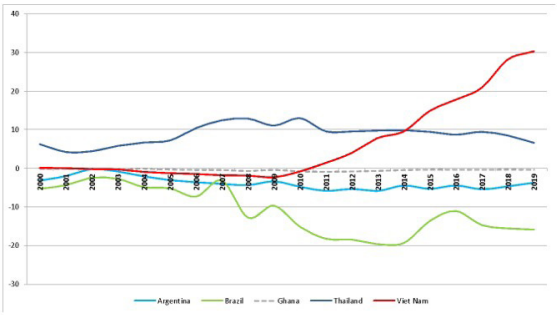


Source: Own elaboration based on UNIDO database.

performance has a reflection in foreign trade, especially in terms of goods linked to the Information and Communication Technologies (ICT). These goods are traditionally connected with a robust digital infrastructure. In this regard, Vietnam was the only country with a growing surplus over 2000 to 2019 (Graph 2).

The evidence presented in this section has a descriptive nature and is intended primarily to set the scene for the analysis of the process of digital adoption by industrial firms in those countries. It was shown that all five countries can be characterized as developing economies, with wide differences existing among them. Location, size, economic dynamism, income structure, productive development, engagement in trade in relatively sophisticated products, and ICT engagement vary considerably. From such a rapid description, it is expected that the evidence about DBT will also reveal differences among and within each one of them.

GRAPH 2
ICT trade balance (2000-2019) - Current USD Billion



Source: Own elaboration based on UNIDO database.

4. Surveys and dataset

The first survey was carried out in Brazil in 2017 as part of the I2027 initiative (INSTITUTO EUVALDO LODI, 2018; FERRAZ et al., 2020). The second one was conducted in Argentina in 2018 (ALBRIEU et al., 2019). The surveys from Ghana, Thailand and Vietnam were carried out in 2019 under UNIDO's supervision (UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION, 2019). Firms were selected from directorate of manufacturing firms for each country following the methodology known as Proportional Probabilistic Sampling. This is the most recommended procedure for the building up of samples of small dimensions and relies on the specification of parameters. The parameters used were: number of firms in the sample, margin of error (the acceptable range for the estimated proportion of the population parameter) and the confidence level (probability that the true proportion will be within that range). This sampling technique is the first-choice method for empirical exercises such as the one performed in view of the simplicity of the sample work.

All surveys addressed the issue of digital adoption in a similar fashion and a common core of questions. The DBT generations were classified into four categories[5], starting from a basic level of digitalization

[5] For details regarding the digital generation approach see Ferraz (2021).

where stand-alone devices are used in comparison to the other extreme where an integrated, intelligent, and interconnected production process prevails: (G1) rigid production (first generation); (G2) lean/flexible production (second generation); (G3) integrated production (third generation); (G4) interconnected and intelligent platforms (fourth generation). The DBT generations were defined for five business functions of a firm: supplier relations, production management, client relations, product development, and business management. Moreover, three sets of questions were put to firms: (1) what generation of digital solution is currently being adopted; (2) what generation of digital solution is expected to be in use in the next 5 to 10 years; and (3) how firms are currently preparing themselves for the projected future (doing nothing, studying, planning and actions in place). Such approach allows for the foresight exercise to be grounded in actual possible actions thus closing the scope for speculative expectations.

As each survey has unique sector and size specifications, in order to build a comparable dataset and produce effective inter-country analysis results, three essential methodological steps had to be taken. The first step was to extract, from each one, only firms operating in the same sectors as the other surveys. The second step was to eliminate firms that did not fully answered questions related to their current or expected digital technology adoption. Such procedure ensured consistency of results and allowed the mitigation of possible incongruences in the responses.

After those two steps, the original dataset composed of 1,730 respondents was reduced to 1,212 firms. Finally, the third step consisted in organizing the panel according to two structural variables: the size of firms and the sector of origin. Two sizes[6] ranges were specified: large firms, with 100 employees or more and small firms, with less than 100 employees. Sector-wise, firms were classified as either

[6] Due to a better comparison between the countries, the option chosen was to separate the size variable into two groups of analysis: small and large. There is an analytical loss with the little differentiation obtained, but at the same time, it was ensured that size subgroups were not represented by very few firms.

belonging to 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 Organisation for Economic Co-operation and Development (2017, 2022). The H-M-H group includes Automobile and Auto parts, and Electronics. No firms from Ghana were included in such category. The L-M-L group includes Food and Textile and, only in Ghana case, Furniture, Metal products and Plastic (Table 2).

TABLE 2
Panel data description by size and technology intensity industries

Country	Size	Technology Intensity		Total
		H-M-H	L-M-L	
Argentina	Large	9	4	13
	Small	95	96	191
	Total	104	100	204
Brazil	Large	103	106	209
	Small	90	47	137
	Total	193	153	346
Ghana	Large	0	30	30
	Small	0	170	170
	Total	0	200	200
Thailand	Large	43	18	61
	Small	71	68	139
	Total	114	86	200
Vietnam	Large	43	44	87
	Small	79	96	175
	Total	122	140	262
Total		**533**	**679**	**1212**

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: Own elaboration based on country-level data from UNIDO and author's database.

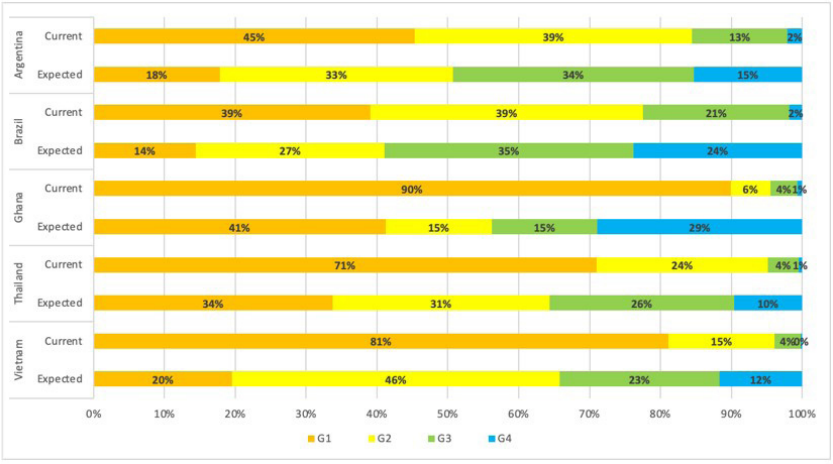
5. Similarities and differences in digital adoption

5.1 Determining current and expected digitalization

The overall picture regarding current adoption is quite straightforward: most firms in the five-country panel are lagging

relatively to more advanced digital technologies (Graph 3). From the statistics, 60.4% and 26.8% of firms from all countries adopt G1 and G2 technologies, respectively. Only 1.6% of the 1,212 firms declared to adopt the most advanced digital technologies available.

GRAPH 3
Current and expected digital adoption ratio by country level



Source: Own elaboration based on country-level data from UNIDO and author's database.

However, the five-country projections for the future indicate increasing differences. Firstly, about 57.2% of firms hope to be at G3 or G4 in the years to come. That is, most firms are projecting a future in which digital technologies are expected to be used to integrate and interconnect all business functions (G3) and even to integrate, connect, and use very advanced technologies to support and take over decision-making processes (G4). To ascend from a G1/G2 dominated reality to a G3/G4 projected scenario though is not straightforward.

Secondly, those pronounced differences among countries must be highlighted. Ghana projects the highest advances in the panel: while presently, 95.5% of firms placed themselves at G1 and G2, in five to ten years 28.9% of this panel hope to be at G4 and 14.9% at G3. Such expected progress finds some resonance in other countries as

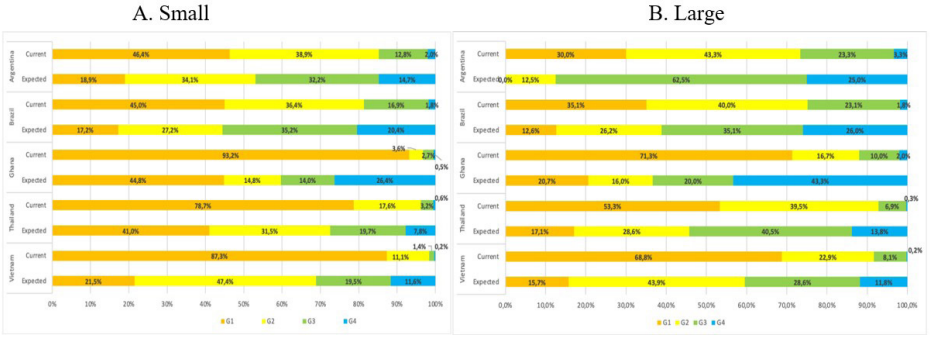
well. For Brazil, almost a quarter of the panel expects to reach G4 in five to ten years, compared to a small group of 1.8% in the present. In addition, while 77.6% are currently at G1 and/or G2, such group is reduced to 41% in the future. The contrast within the five-country group escalates relatively to current adoption levels. While above 90% of firms from Thailand or Vietnam are currently at G1 and/or G2, in the future such proportion decreases to just about 65%.

The five-country panel also suggests relevant differences among and within countries in relation to two structural features of firms: size and sector. In terms of size, the larger the firm, the more advanced digital generations they are relatively to their smaller peers (Graph 4). This result came as no surprise, because, as argued and demonstrated by the literature[7], larger firms have access to information and resources to invest in modernization. If DBT adoption strengthens competitiveness, such higher probability of larger firms adopting more advanced digital technologies would eventually enhance their already strong market positions. The inter-country comparison indicates that in Ghana, Thailand and Vietnam, currently large firms tend to place themselves in a slightly more advanced position than small firms do: the concentration of small firms is higher in G1, while there are more large firms in G2. Brazil and Argentina tend to have a lower proportion of small firms in G1 and G2 in comparison with other countries.

In terms of expectations of adoption in relation to current adoption, the differences among countries are also more pronounced by firm size. In Argentina, large firms intend to evolve from G2 and G3 currently (43.3% and 23.3%, respectively) to G3 and G4 in the future (62.5% and 25.0%). Regarding small firms, 85.2% currently adopt either G1 or G2 and, in the future, intend to move towards G2 and G3 generations (66.4% of firms), with only 14.7% adopting G4 technologies. Such stepwise Argentine pattern is also to be found in Thailand and Vietnam even if with less pronounced expectations for the future. Currently, in Thailand and Vietnam above 90% of firms

[7] Ferraz et al. (2020) found the same result for an amplified survey of Brazilian industrial firms.

GRAPH 4
Current and expected digital adoption by firm size. *Note:* **Large: 100 or more employees; Small: less than 100 employees.**



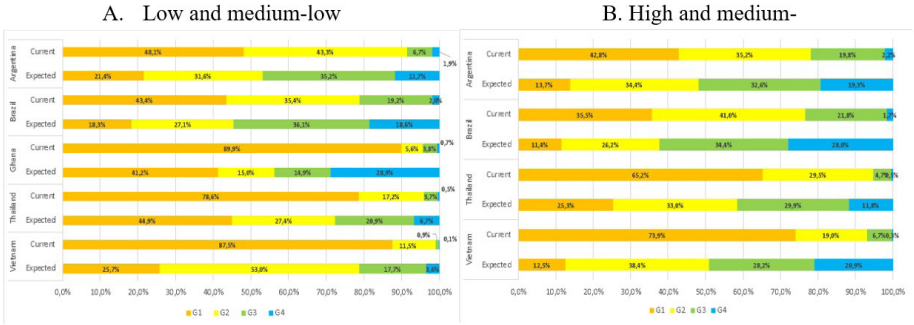
Source: Own elaboration based on country-level data from UNIDO and author's database.

adopt either G1 or G2, regardless the size. In the future, the majority of large Thai firms (69.1%) expect to adopt either G2 or G3 and almost 13.8% of firms hope to reach the most advanced digital generations. In contrast, 72.5% of small firms will remain at either G1 or G2. In Vietnam the pattern is similar, with large firms located at G2 or G3 and small firms at G1 or G2, in the future. What calls the attention of the Vietnam case is the fact that it is the only country where the expectations of small firms towards more advanced digital technologies is quite the same in comparison with the expectations of large firms.

Finally, a dichotomic pattern apparently prevails in Ghana. While 95.5% of firms currently adopt G1 or G2, with a larger proportion of large firms adopting G2 (16.7% against 3.6% for small firms), expectations for the future show a higher proportion of large firms aiming to adopt either G3 (20.0%) or G4 (43.3%).

Another important structural dimension is the digital adoption by sector classified according to their technology intensity (Graph 5). Such grouping could be done for Argentina, Brazil, Thailand, and Vietnam, but not for Ghana, where all firms belonged to low or medium-low-technology intensity sectors. The overall pattern also brings no surprises: regardless the country, the higher the technology intensity of firms, the more advanced they are likely to be in the current adoption of advanced DBT. Equally, in time, high and medium-high-technology

GRAPH 5
Current and expected digital adoption by technology intensiveness. *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 Industries firms were interviewed.**



Source: Own elaboration based on country-level data from UNIDO and author's database.

intensity firms intend to adopt more advanced DBT compared to their lower technology intensity peers. Currently, the concentration at G1 is very marked in Thailand and Vietnam, regardless of the sector of firms, but with a slightly lower proportion of high-technology intensity firms at G1: 67.5% for medium-high and high-technology intensities versus 81.4% for low- and medium-technology industries for Thailand and 77.1% and 88.6%, respectively, for Vietnam.

In Argentina and Brazil around 40% of firms in both groups of sectors adopt G2 technologies. The difference emerges in the adoption of G3 by firms of each group of sectors and countries. While the proportion of high- and medium-high-technology intensity firms is similar in both countries (between 28% and 26%), the one for low- and medium-low-technology intensive firms differs. In Argentina, a significant amount (43.9%) of low- and medium-low-technology intensity firms adopts G1 and only 6.6% adopt G3. In Brazil a third of firms in the same group declared to use G1 and 23% indicated G3. Thus, low- and medium-low-technology intensity firms in Brazil seem to be farther ahead than their counterparts are in Argentina, as well as from Ghana, Thailand and Vietnam.

Significant progress is expected in the future, especially by high and medium-high-technology firms: only a small proportion (between

11.4% and 25.3%) of firms from Argentina, Brazil, Thailand and Vietnam expect to remain at G1 and between 11.8% and 28% expect to adopt G4 digital technologies, with the highest expectation for Brazil. Country-based differences among low- and medium-low-technology intensity is higher. In Brazil, 18.3% expect to remain at G1 in five to ten years ahead; in Argentina this amount is 21.4%, for Vietnam 25.7%, Ghana 41.2% and for Thailand is 44.9%. So, the variation between them is not negligible.

Argentina and Brazil present a similar evolution toward the future. Between 51.9% and 62.4% of the high and medium-high firms, respectively, expect to adopt G3 or G4, regardless of the technology intensity of the sectors. This would be quite remarkable progress as currently only between 22% and 23.4% of firms are at a similar stage of adoption. In Argentina, the difference between high and medium-high-technology and low and medium-low-technology intensity sectors expecting to adopt G4 is less marked than in Brazil.

In Thailand, the high and medium-high-technology firms are currently concentrated in G1 and G2. In five to ten years, most firms in this group (62.9%) intend to evolve toward 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 (72.3%), and only 6.7% of this group projects to be in G4 in the future. In Vietnam, the evolution pattern is not straightforward. While currently most firms adopt G1 (87.5% of low- and medium-low-technology firms and 73.9% of high and medium-high-technology firms), expectations for the future vary across sectors. Around 49.1% of high and medium-high-technology firms expect to be at the G3 and G4 level in five to ten years. In the low and medium-low-technology segment only 21.3% of the panel expect to be in G3 and G4.

5.2 Determining digital readiness

At the country level, the current adoption of digital technologies by firms from developing countries is timid, but when they project

their future adoption, they expect to move forward in a significant way. This is a positive signalization, but such expectations must be grounded on concrete actions, as the evolution from lower generations to more advanced DBT is not a linear process since significant changes to organizational structures and capabilities are required and current mobilization efforts must be undertaken to prepare themselves for the future (*readiness*). Concerning the projected DBT generations, firms were asked to declare in the surveys whether currently: (i) no current action is in motion; (ii) studies are on the way; (iii) actions are being planned or, (iv) plans are in motion: concrete actions are being taken to build the future. It is thus assumed that different mobilization efforts suggest how expectations are "anchored" in the various types of action, indicating a lower or higher probability of firms to effectively being able (or not) to achieve the projected generation of digital technologies.

Current and expected DBT digital technology adoption and preparedness for the future provide information about different patterns of potential digital adoption. To synthesize this information, one index was developed along two steps. The first step consisted in proposing the following three indicators:

- **1. Average Current Digital Adoption**: $G_0 = \frac{\sum_{i=1}^{5} CDA_i}{5}$, where CDA_i is the current digital adoption for the business function *i* and is contained in the range $1 \leq CDA_i \leq 4$, since only four digital generations are predicted. So, G_0 will be the average current digital adoption and will vary from 1 to 4.

- **2. Average Expected Digital Adoption:** $G_f = \frac{\sum_{i=1}^{5} EDA_i}{5}$, where EDA_i means the expected digital adoption for the business function *i.* The variable G_f follows the same rule as above.

- **3. Average Readiness Level:** $RL = \frac{\sum_{i=1}^{5} RL_i}{5}$, where RL_i means the readiness level for the business function *i.* As the current and expected digital adoption, the readiness level also has four categories of action: (1) no action, (2) studying, (3) have a plan and (4) have

a plan under execution. In the same way, RL will also vary from 1 to 4 as an average.

The second step consisted of using these three indicators to design a synthetic index called Digitalization Readiness Index (DRI). DRI is intended to reveal a firm's announced course of action as a measure of the probability of effectiveness to reach the projected DT generation. In this sense, DRI combines the current and expected DT generation of a firm with what the firm is currently doing in terms of actions to reach the desired DT generation in the future. The expression for DRI is described as follows:

$$DRI = G_0 + \left(G_f - G_0\right) * \alpha \quad (1)$$

where α is an action parameter defined as $(RL - 1)/3$.

More than the absolute value of the DRI index, classifying firms according to their potential digital adoption became relevant for this analysis as it allows the immediate appreciation of where a country is located in comparison to the others and, within it, where the set of firms organized by sector or size stands at.

Inspired by Abramovitz (1986), the DRI values allow to establish patterns of adoption timing in a specific period according to three categories (Figure 1). Category 1 configures the **lagging behind** position, that is, a firm considered in a backward position in terms of current and future DT adoption and mobilization efforts (mostly G1 and/or G2 with no significant mobilization efforts). Category 2 configures the **catching up firm,** the case of firms that are at least at G2 and/or G3 in the projected future and have some level of mobilization efforts. Category 3 characterizes the **forging ahead** firm, that is, firms that are at G3 and/or G4 currently and in the future with a consistent mobilization effort.

In aggregated terms, the patterns of digital adoption are quite straightforward: 68.2% of firms from the five-country panel are lagging behind; 24.0% are trying to catch-up; and only 7.8% can be classified as forging ahead: firms which adopt more advanced technologies

FIGURE 1
DRI Position According to the average of current adoption, expected adoption and readiness level. ***Note*****: L = lagging behind; C = catching up and F = forging ahead**

Average of G0	Average of Gf	Average of Readiness 1-2	2-3	3-4
1-2	1-2	L	L	L
	2-3	L	L	C
	3-4	L	C	C
2-3	2-3	L	C	C
	3-4	C	C	F
3-4	3-4	F	F	F

Source: Authors' elaboration.

compared to their peers and are willing to evolve even further in the future, having plans in action to reach this projected future (Table 3).

In terms of countries specificities, Argentina and Vietnam present a similar result: a large base where lagging behind firms is located at an intermediate and smaller group of catching up firms, and an upper group for the elite of forging ahead firms with between 4.6% to 8.2% of the total of these two countries. Ghana and Thailand are also similar but, in their case, there are a larger number of firms in lagging behind condition (more than 85% for both), with a small group from each country considered as moving forward. The Brazilian pattern is different in comparison to the others since it has the highest proportion of firms catching-up and forging ahead: 32.1% and 15.9%, respectively.

In terms of size, for all countries larger firms perform better than their smaller peers but with some country specificities. In Argentina, a small proportion of larger firms is moving forward (7.7%), and most of the panel is catching up (76.9%); in contrast, 71.6% of small firms are lagging behind, 20.2% is catching up, and only 8.2% is forging ahead. In fact, Argentina is the only case where smaller firms are proportionately more in the forging ahead condition than larger firms. In Ghana case, the size difference is quite the same but less pronounced: 65.2% of large and 91.2% of small Ghanaian firms are lagging behind; only 8.7% of large firms is moving forward, and 2.9% of small firms is doing so. For Thailand most firms are lagging behind, regardless their size. Most of Vietnamese firms are lagging behind (48.3% of large

TABLE 3
Digital Readiness Index by size and tech-intensity industry
(% firms over the total by country)

Size			
Country	**Lagging Behind**	**Catching-up**	**Forging Ahead**
Total	**68.2**	**24.0**	**7.8**
Large	53.9	32.6	13.5
Small	75.4	19.7	4.9
Argentina	**67.9**	**24.0**	**8.2**
Large	15.4	76.9	7.7
Small	71.6	20.2	8.2
Brazil	**52.0**	**32.1**	**15.9**
Large	48.8	33.0	18.2
Small	56.9	30.7	12.4
Ghana	**87.7**	**8.6**	**3.7**
Large	65.2	26.1	8.7
Small	91.4	5.8	2.9
Thailand	**88.0**	**11.0**	**1.0**
Large	83.6	14.8	1.6
Small	89.9	9.4	0.7
Vietnam	**62.5**	**33.0**	**4.6**
Large	48.3	39.1	12.6
Small	69.5	29.9	0.6
Technology intensity			
Total	**68.2**	**24.0**	**7.8**
H-MH	57.1	31.5	11.4
L-ML	77.3	17.9	4.9
Argentina	**67.9**	**24.0**	**8.2**
H-MH	57.6	30.3	12.1
L-ML	78.4	17.5	4.1
Brazil	**52.0**	**32.1**	**15.9**
H-MH	49.2	31.1	19.7
L-ML	55.6	33.3	11.1
Ghana	**87.7**	**8.6**	**3.7**
L-ML	87.7	8.6	3.7
H-ML	n/a	n/a	n/a
Thailand	**88.0**	**11.0**	**1.0**
H-MH	85.1	14.0	0.9
L-ML	91.9	7.0	1.2
Vietnam	**62.5**	**33.0**	**4.6**
H-MH	43.0	49.6	7.4
L-ML	79.3	18.6	2.1

Note: H-MH = High and Medium-High; and L-ML = Low and Medium-Low
n/a = not available
Source: Own elaboration based on country-level data from UNIDO and author's database.

and 69.5% of small firms), but the proportion of large firms forging ahead is much higher in comparison to the smaller ones. Brazil is the country with the highest proportion of firms, independently of the size, in forging ahead condition.

Regarding the technology intensity, as shown in Table 3 the overall picture is similar to what was found concerning the current and expected adoption: firms from high and medium-high-technology intensity sectors stand better prepared than firms from low and medium-low-technology intensity firms. In addition, the pattern differs across countries, though some similarities can also be found.

In Argentina and Vietnam, the percentage distribution of firms among the three categories of potential digital adoption is similar. However, the distribution by sector is different. In the Argentinian case, around 58% of high or medium-high-technology firms are lagging behind, while in Vietnam this proportion is 43%, with a higher concentration in catching-up firms. For the low and medium-low-technology firms, in both countries they are heavily lagging behind (almost of 80% of the panel). On the other side, firms in Thailand are heavily lagging behind (80%), regardless of the sector. Finally, in Brazil, at least 19.7% of high and medium-high-technology firms are moving forward, and 11.1% of low and medium-low-technology firms are doing so.

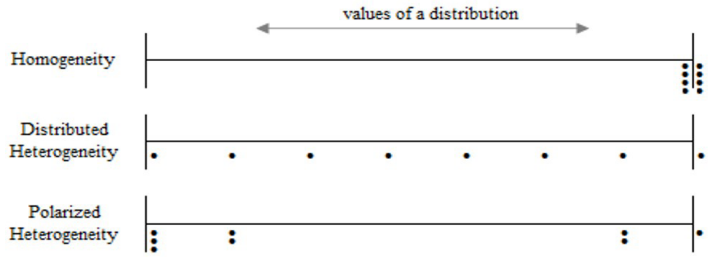
In summary, each country seems to have a particular Digital Readiness profile, and differences among them are significant. The structural features of firms shed light on why diversity and heterogeneity exist: the larger its size and the higher technology-intensive is the sector the firm belongs, the better placed a firm is to catch up or to forge ahead its digitalization plans. Further considerations and analysis of the digital heterogeneity of this five-country panel can be accessed in the next section.

5.3 Determining digital heterogeneities

Heterogeneity can be defined as the antithesis of homogeneity. Homogeneity is the representation of a perfect equality among parts.

In a distribution, homogeneity is the situation in which all values are equal, independently if these values are very high or very low (Figure 2). Any situation out of homogeneity defines different types of heterogeneity. Heterogeneity can be presented in at least two cases. The first one is where the values of the distribution are all different and are, on some degree, symmetrically distant. This is the distributed heterogeneity situation. The second one is where some values of the distribution can be equal in specific groups, but they are expressively distant, ones from the others. This is the polarized heterogeneity situation.

FIGURE 2
Homogeneity and situations of heterogeneity

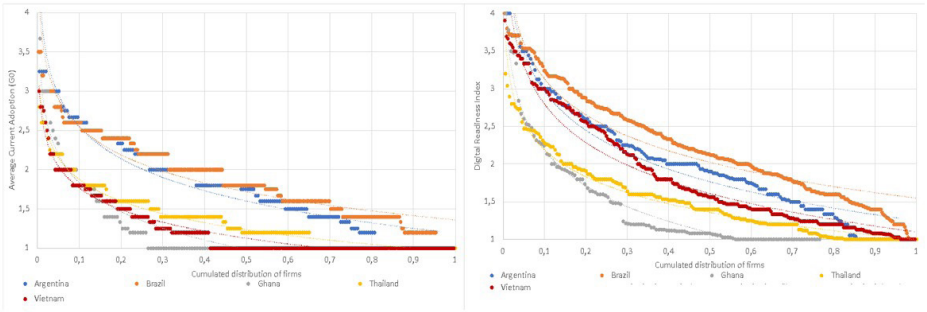


Source: Author's elaboration.

As already mentioned, the survey provided information about three kinds of digital adoption: the Average Current Digital Adoption (G_o), the Average Expected Digital Adoption (G_f), and the potential adoption as defined by the *DRI* index. Graph 6A shows the distribution of the G_o values for the five selected countries by cumulated percentiles and the log-curves of adjustment.

As observed, current adoption in Vietnam and Ghana follow a Polarized Heterogeneity distribution, in which only less than 10% of the distribution reaches the maximum values around G3 and a large share of firms (between 60% and 70%) are still at G1. In contrast, Argentina and Brazil follows a Distributed Heterogeneity of the current adoption

GRAPHS 6A and 6B
Current and Potential Digital Adoption. Distribution by cumulated percentile of firms



A. Current adoption B. Potential adoption (DRI)

Source: Own elaboration based on country-level data from UNIDO and author's database.

values among firms with maximum values at around 3,5. Thailand presents an intermediate situation. The maximum value of current adoption is around 3, but the values are distributed by groups. That is, a large group of firms report the same level of current adoption. This large groups stands in values between 1 and 1,6.

The log-adjustment of the distribution allows a perception of the differences in the expected digital advance among countries. First, the closer the curve resembles a straight line with the same slope along it, the more it converges to the condition of distributed heterogeneity. Second, a more outward curve indicates that, for the same cumulated percentile, the country stands in more advanced generations. Graph 6A confirms that Brazil and Argentina tend to be more digitally advanced comparing to Thailand, Vietnam, and Ghana, respectively.

Graph 6B reports the distribution of the potential adoption value for each country. By the slope of the log-adjusted curve, all countries will present a better adoption performance in the future. Brazil and Argentina still show more outward curves. However, Vietnam gets a similar position to Argentina in the first 30% of the distribution, standing above Thailand. In terms of the different situations describing heterogeneity, no significant changes come out. Ghana and Vietnam still present a Polarized Heterogeneity, maybe even more stressed given that the maximum values will place around G4 in Ghana and above G3 in

Thailand. Argentina and Brazil still present a Distributed Heterogeneity that may be increased given that the maximum values will place in G4. Vietnam seems to change from a Polarized Heterogeneity to a Distributed Heterogeneity, especially due to a large proportion of firms that reported standing in G1 will foreseeably adopt more advanced generations.

To move on towards a conceptualization of digital heterogeneity, the traditional concept of structural heterogeneity is used to take into account not only how different are the values of the distribution, but also, the distances of each value to an 'optimal' value of efficiency. In terms of digital adoption, such optimum value is given by the 'best practice' in relative and absolute terms. In absolute terms, the best practice is the world technology frontier represented by G4. In relative terms, the best practice is a local digital frontier given by the highest performed adoption by firms in a specific country, and it can take values from G1 to G4. Following this, a general specification for a digital heterogeneity indicator is:

$$H = \frac{1}{n}\sum_{i=1}^{n}\left(X_i - X^*\right)^2 \tag{2}$$

where heterogeneity (H) measures the mean of the square of the distances between the X_i values of the distribution and the optimum value in absolute or relative terms $\left(X^*\right)$. The H indicator takes value zero in the case of total homogeneity. That is, when all the values of the distribution are placed in the optimum value. Higher values are taken when heterogeneity is also higher. Considering the variables at the firm-level, current adoption (G_0), expected adoption (G_f), and the potential adoption (DRI), the following indicators can be defined to identify situations of Polarized Heterogeneity of digital adoption:

- Heterogeneity of current adoption

$$AH^j\left(G_0^j\right) = \frac{1}{n}\sum_{i=1}^{n}\left(G_0^{ij} - G_0^{max}\right)^2 \tag{3}$$

$$RH^j\left(G_0^j\right) = \frac{1}{n}\sum_{i=1}^{n}\left(G_0^{ij} - G_0^{j-max}\right)^2 \tag{4}$$

Where $AH^j\left(G_0^j\right)$ and $RH^j\left(G_0^j\right)$ represent the heterogeneity of current adoption calculated on absolute and relative optimum values respectively; G_0^{ij} is the medium current adoption of the i-firm in the j-country; G_0^{j-max} is the best performed adopted generation in the j-country; and G_0^{max} is the absolute best practice represented by G4.

- Heterogeneity of expected adoption

$$AH^j\left(G_f^j\right)=\frac{1}{n}\sum_{i=1}^{n}\left(G_f^{ij}-G_f^{max}\right)^2 \tag{5}$$

$$RH^j\left(G_f^j\right)=\frac{1}{n}\sum_{i=1}^{n}\left(G_f^{ij}-G_f^{j-max}\right)^2 \tag{6}$$

Where $AH^j\left(G_f^j\right)$ and $RH^j\left(G_f^j\right)$ represent the heterogeneity of expected adoption calculated on absolute and relative optimum values respectively; G_f^{ij} is the medium expected adoption of the i-firm in the j-country; G_f^{j-max} is the best expected generation in the j-country; and G_f^{max} is the absolute best practice represented by G4.

- Heterogeneity of potential adoption

$$AH^j\left(DRI^j\right)=\frac{1}{n}\sum_{i=1}^{n}\left(DRI^{ij}-DRI^{max}\right)^2 \tag{7}$$

$$RH^j\left(DRI^j\right)=\frac{1}{n}\sum_{i=1}^{n}\left(DRI^{ij}-DRI^{j-max}\right)^2 \tag{8}$$

where $AH^j\left(DRI^j\right)$ and $RH^j\left(DRI^j\right)$ represent the heterogeneity of potential adoption calculated by the DRI index on absolute and relative optimum values, respectively; DRI^{ij} is the medium DRI value in the i-firm and in the j-country; DRI^{max} is the maximum value of the DRI indicator, which is equal to 4; and DRI^{j-max} is the maximum value of the DRI indicator in the j-country.

The results for the heterogeneity indicators are presented in Table 4. Ghana shows the highest values of current heterogeneity both in relative and absolute terms, and there are no differences between them. For the rest of the countries, the current heterogeneity in relation to their own

TABLE 4
Heterogeneity of current, expected, and potential adoption

Indicators		Argentina	Brazil	Ghana	Thailand	Vietnam
Current Adoption	$RH^j\left(G_0^j\right)$	2.57	2.94	6.26	2.25	3.24
	$AH^j\left(G_0^j\right)$	3.98	3.51	6.26	5.52	6.03
Expected Adoption	$RH^j\left(G_f^j\right)$	2.96	2.32	5.53	3.47	3.67
	$AH^j\left(G_f^j\right)$	2.96	2.32	5.53	4.2	3.67
Potential Adoption	$RH^j\left(DRI^j\right)$	4.65	3.64	7.37	3.11	4.87
	$AH^j\left(DRI^j\right)$	4.65	3.64	7.37	6.46	5.26
$\left[RH^j\left(G_f^j\right)/RH^j\left(G_0^j\right)\right]-1$		0.15	-0.21	-0.12	0.54	0.13
$\left[AH^j\left(G_f^j\right)/AH^j\left(G_0^j\right)\right]-1$		-0.26	-0.34	-0.12	-0.24	-0.39
$\left[RH^j\left(DRI^j\right)/RH^j\left(G_0^j\right)\right]-1$		0.81	0.24	0.18	0.38	0.5
$\left[AH^j\left(DRI^j\right)/AH^j\left(G_0^j\right)\right]-$		0.17	0.04	0.18	0.17	-0.13

Source: Own elaboration based on country-level data from UNIDO and author's database.

best practice is quite similar in Argentina, Brazil, Thailand, and Vietnam. However, when considered the absolute optimum value that represents the best practice, heterogeneity takes higher values and countries show amplified differences among them. Higher values mean greater distances to the best practice (G4). Therefore, the *AH* indicator reveals the differences in the adopted generation in which they really are. Argentinian and Brazilian firms are closer to the best practice than Ghana, Thailand, and Vietnam. For that reason, the absolute heterogeneity is relatively lower.

Heterogeneity in expected adoption means how firms differ in their own vision about which generation will be adopted in the next ten years. As the expected adoption can only be at least equal to the current adoption and as the absolute best practice is fixed, it is predictable that the delayers expect to advance more than the leaders, and therefore, a natural convergence of expectative towards the best practice will take

place. Nevertheless, divergence can happen if firms in intermediate generations (2 or 3) expect to advance, and the delayer firms (generation 1 or 2) expect to remain in the same digital generation. Divergence can also happen in relative heterogeneity since the best practice in a country can move when the best practice in current adoption is not G4. In this case, some firms can expect to adopt G4 while others expect to stand or to make less ambitious advances, what will reflect in heterogeneity.

The results show that, as anticipated, the absolute heterogeneity in expected adoption is lower than the absolute heterogeneity in current adoption. Among countries, firms differ more in their absolute heterogeneity of expected adoption in Ghana and Thailand, while Brazil and Argentina show less heterogeneity in their expected adoption given that they are already closer to the best practice. However, the relative heterogeneity in expected adoption is higher than in current adoption in all countries except for Brazil and Ghana. In the case of Brazil, this is due to a higher proportion of firms that are already in G4. As the best practice is at a fixed value, any advancement of the delayed firms represents the convergence of expectation towards the local frontier. The case of Ghana is different. In Ghana, a large share of firms converges to the same expectation of digital adoption of G4 in the next years no matter what their starting point.

The evaluation of heterogeneity in terms of potential adoption allows a more revealing picture of adoption patterns in the next five to ten years, considering not only the expectations of firms but also their readiness efforts. Absolute and relative heterogeneity take similar values in Argentina, Brazil, and Ghana. This is because the local and international best practices estimated by the DRI indicator are the same. In comparative terms, Ghana shows the highest level of heterogeneity of potential adoption. There are no strong differences among the rest of the countries regarding their local best practice. However, in terms of the international frontier, Thailand and Vietnam show quite higher levels of potential heterogeneity than Argentina and Brazil.

The comparison of potential with the current adoption shows that absolute and relative digital heterogeneities may increase for all countries

in the years to come. This evidence suggests that technical change may generate asymmetries along the process of technology adoption. In terms of relative heterogeneity (the relation with the local best practice), although there are no relevant differences among countries, the highest increases are for Argentina and Vietnam, while the lowest is for Brazil and Ghana. A growth of relative heterogeneity in potential adoption means that when the local best practice advance, the differences in adoption increase, that is, adoption goes on faster in the generations closer to the optimum than in the lower generations. This is what is happening in Argentina, followed by Vietnam and Thailand, with more intensity than in the rest of the countries. Vietnam, as predicable, reduces its absolute heterogeneity because of the reduction on its degree of polarization.

6. Digital heterogeneities in developing countries

This paper provided evidence for a panel of 1,212 manufacturing firms from five developing countries - Argentina, Brazil, Ghana, Thailand, and Vietnam - about the current and prospective adoption of different generations of digital technologies, and the mobilisation efforts by firms to achieve the intended future. Even if these countries are structurally different, in terms of the process of digitalization in manufacturing two common features stand out.

First, currently, basic generations of digital technologies prevail in Argentina, Brazil, Ghana, Thailand, and Vietnam; in the future expectations are for a significant evolution. However, given the low level of readiness for the future, these positive expectations are in check. Secondly, when the size and sector of firms are taken into consideration, more differences in the pattern of digital adoption among and within countries are revealed. Size matters to differentiate the extent to which firms adopt and expect to adopt digital technologies: the larger the firm, the higher the propensity to adopt more advanced generations. The same result is observed when technology intensity is considered: a firm from a higher technology intensity sector tends to adopt and expect to adopt

digital technologies from the third and fourth generations. These findings come as no surprise and confirm evidence already identified in empirical studies about developed and developing countries.

Nevertheless, each country presents a specific pattern of adoption and evolution towards the future. Two countries (Ghana and Vietnam) reveal a polarized pattern of digital adoption: the contrast or the distance between low and advanced adopters is very striking. Argentina, Brazil, and somehow Thailand shows a more distributed pattern of digital adoption.

The results suggest that absolute and relative heterogeneity of digitalization may increase for all countries. In addition, such an asymmetric process of digital adoption may have competitive implications. If digitalization leads to competitive advantages, where large firms in high and medium-high-technology industries are better placed to introduce digital technologies compared to their small and lower-technology-intensity peers, changes in market structures may occur towards higher concentration relatively to current levels. It is beyond the scope of the present study to further analyse the reasons for such differences and the impact of these asymmetries on other relevant parameters regarding the economic structure. However, the evidence presented is a call for an organized reflection around the theme since the digitalization process, when carried out in isolation and, in turn, restricted to firms with well-established capabilities, can accentuate the traditional structural heterogeneity present in developing countries. So, a topic for further consideration is how the scope of policies can emphasize and support the relevance of digital adoption for small and less technological firms.

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