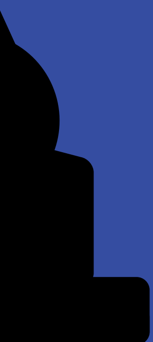

Made in Latam

How smart manufacturing can give Latin America new hope for industrialization

Nicolás Grosman
Hernán Braude
Sebastián Rovira
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United Nations
ECLAC

eLAC·2022
Digital Agenda for Latin America and the Caribbean

대한민국정부
The Government of the Republic of Korea

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This document was prepared by consultants Nicolas Grosman and Hernan Braude, in collaboration with Sebastián Rovira and Alejandro Patiño, from the Innovation and New Technologies Unit of the Production, Productivity and Management Division of the Economic Commission for Latin America and the Caribbean (ECLAC). The study was conducted in the framework of the activities of the cooperation programme for 2019 between the Republic of Korea and ECLAC.

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Glossary[1] and acronyms

Glossary

- Additive manufacturing: Commonly known as 3D printing, the use of special printers to create three-dimensional physical objects from 3D model data by adding layer upon layer through material extrusion, directed energy deposition, material jetting, binder jetting, sheet lamination, vat polymerization and powder bed fusion. Additive manufacturing is contrasted with subtractive manufacturing methods, which use molds or rotating milling cutters to remove material from a solid block of material.
- Advanced manufacturing: Manufacturing systems in industrial sectors and industrial production characterized by the technology associated with the fourth industrial revolution, such as digital production technologies, nanotechnology, biotechnology and new and improved materials.
- Advanced digital production technologies: Technologies that combine hardware (advanced robots and 3D printers), software (big data analytics, cloud computing and artificial intelligence) and connectivity (the Internet of Things). Advanced digital production technologies are the latest evolution of digital technologies applied to production; a core technological domain associated with the fourth industrial revolution. They give rise to smart production —also referred as the smart factory, or Industry 4.0.
- Artificial intelligence: The branch of computer science seeking to simulate the human capacity to reason and make decisions. The term usually refers to such artificial intelligence techniques as machine learning, deep learning, neural networks, fuzzy logic, computer vision, natural language processing and self-organizing maps to provide machines and systems with human-like cognitive capabilities, such as learning, adapting, perceiving and

[1] Adapted mostly from: United Nations Industrial Development Organization, 2019. Industrial Development Report 2020. Industrializing in the digital age. Vienna.

solving problems. Artificial intelligence can be defined as making computers intelligent and capable of mimicking and predicting human behaviour and solving problems as well as or better than humans.

- Big data: Data characterized by unprecedented volume; frequency or speed of being generated, made available and altered; variety of sources, format and complexity, either unstructured or structured; and granularity. Such data require new forms of processing to enable their use for enhanced decision-making and process optimization. Big data analytics refers to techniques and technologies that allow voluminous machine-readable data to be generated, stored, accessed, processed and analyzed to uncover valuable information —patterns, correlations, trends and preferences— that can help organizations make informed decisions.
- Cloud computing: On-demand network use of a shared pool of configurable computing resources such as networks, servers, storage, applications and services that can be rapidly accessed or released with minimal management effort or service provider interaction. Cloud computing services are used over the internet to access software, computing power, storage capacity and the like, where ubiquitous and convenient services are delivered from the server or the service provider; can be scaled up or down, can be used on demand, and are paid for according to capacity used, or else are pre-paid.
- Computer-aided design and manufacturing: Use of computer systems (both hardware and software applications) to design and draft technical drawings and models and to provide instructions for and control machine tools and equipment to make prototypes, finished products and whole production runs. Computer-aided design systems allow building and viewing a design in three-dimensional space, and they facilitate manufacturing by conveying information on materials, processes, dimensions and tolerances. Computer-aided design can be used by itself, or it can be integrated with and provide inputs to other computer-aided software such as computer-aided manufacturing, which controls the machine tool that creates or assembles the physical product.
- Collaborative robot (cobot): A robot that physically interacts with humans. Designed to learn new tasks, cobots are built with passive compliance features and integrated sensors to adapt to external forces. Cobots are typically safe, cost-effective, easy to use and suitable for small-scale production and reduced production cycles. They are also portable and easy to configure and reconfigure for different tasks.
- Digital showrooms: learning factories and demonstrators that help companies get some first-hand experience on digital solutions. Companies and their employees are provided a testing environment in which experts help them to familiarise themselves with the latest technology in simulated production processes
- First generation technologies (rigid production): the use of digital technologies (DTs) for a specific purpose within a specific function (e.g., CAD in product development).
- Fourth generation technologies (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).
- Fourth industrial revolution: The latest wave of technological breakthroughs. The first industrial revolution, between 1760 and 1840, was triggered by the steam engine and featured the mechanization of simple tasks and the construction of railroads. The second, between the late 19th century and the early 20th century, rose with the advent of electricity, the assembly line and mass production. The third, since the 1960s, was driven by the development of semiconductors and mainframe computing, together with the introduction of personal computers and the internet. The fourth industrial revolution is based on the growing convergence between different emerging technology domains, including digital production technologies, nanotechnology, biotechnology and new and improved materials.

- Internet of Things: The next iteration of the internet, where information and data are no longer predominantly generated and processed by humans (as most data created so far have been) but by interconnected smart objects, embedded in sensors and miniature computers that sense their environment, process data and engage in machine-to-machine communication. Internet of Things relies on interconnections through the internet's network of devices, machinery and objects, each uniquely addressable based on standard communication protocols.
- Machine-to-machine: Direct communication or data exchange between machines, or between machines and devices or components. Machine-to-machine communication encompasses two types. One is machine-to-machine wireless communication with no human intervention. The other is machine-to-mobile and mobile-to-machine communication between mobile devices and machines. Web-based machine-to-machine communication relies on normalized technologies and standardized protocols/formats. The interconnection of more machines able to communicate is known as Internet of Things (IoT).
- Machine learning: An application of artificial intelligence, machine learning systems use general algorithms to figure out on their own how to map inputs to outputs, typically being fed by very large sample datasets. These systems can improve their performance on a given task over time by amassing experiences and large volumes of data, such as big data.
- Robot: A machine, programmed by a computer, capable of carrying out a series of more or less complex actions automatically. Robots can be industrial robots or service robots. An industrial robot is an automatically controlled, reprogrammable and multipurpose manipulator in three or more axes, either fixed in place or mobile, used in industrial applications such as manufacturing processes (welding, painting and cutting) or handling processes (depositing, assembling, sorting and packing). A service robot is a machine that has a degree of autonomy and operates complex and dynamic interactions and coordination with persons, objects and other devices (when used, for example, for cleaning, surveillance or transportation).
- Second generation technologies (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).
- Smart factory: Plant applying smart manufacturing. Used in general to refer to the growing computerization and automation of manufacturing plants.
- Smart manufacturing: The application of advanced digital production technologies to manufacturing production. The integration of these technologies includes workers, manufactured products, equipment and machinery along all stages of production in an intelligent system. The system's components interact with and control each other, take decisions and implement actions through digital networks of interconnected equipment and sensors, powered by real-time data analytics, machine learning, machine-to-machine communication and other intelligent algorithms.
- Third generation technologies (integrated production): DTs are integrated and interconnected in all business functions (e.g., enterprise resource planning software applications or web-based sales support systems).
- Testbed: a testbed is a platform and/or environment for conducting rigorous and replicable testing of new technologies.

Acronyms

- ACATECH: German Academy of Science and Engineering
- ADP: Advanced Digital Production
- AGV: Automated Guided Vehicle
- AI: Artificial Intelligence
- ANATEL: National Telecommunications Agency, Brazil
- AR: Augmented Reality
- B2B: Business-to-business
- BMWI: Federal Ministry of Economic Affairs and Energy, Germany
- BNDES: Banco Nacional de Desenvolvimento Econômico e Social
- E2E: Employee-to-employee
- C4IR: Center for the 4th Industrial Revolution
- CIP: Competitive Industrial Performance
- CNI: Confederaçao Nacional da Indústria, Brazil
- DIY: Do-it-Yourself
- DNP: National Planning Department, Colombia
- FINEP: Funding Authority for Studies and Projects, Brazil
- FONATEL: National Telecommunications Fund, Costa Rica
- GCI: Huawei's Global Connectivity Index
- GDP: Gross Domestic Product
- GPT: General Purpose Technologies
- ICT: Information and Communications Technologies
- IDR: UNIDO's Industrial Development Report
- IADB: Interamerican Development Bank
- IICA: Interamerican Institute for Cooperation on Agriculture
- INTI: National Institute of Industrial Technologies, Argentina
- IT: Information Technologies
- IoT: Internet of Things
- LATU: Technological Laboratory of Uruguay, Uruguay
- M2M: Machine-to-machine
- MiCiTT: Ministerio de Ciencia, Tecnología y Telecomunicaciones, Costa Rica
- MID: Ministry of Industrial Development, Argentina
- MinCIT: Ministerio de Comercio, Industria y Turismo, Colombia
- MinTIC: Ministerio de Tecnologías de Información y Comunicación, Colombia
- NL4.0: Nuevo León 4.0 Council, Mexico
- SENA: Servicio Nacional de Aprendizaje, Colombia
- SENAI: Serviço Nacional de Aprendizagem Industrial, Brazil
- SMEs: Small and Medium Enterprises
- UIA: Unión Industrial Argentina, Argentina
- UNIDO: United Nations Industrial Development Organization
- UTU: Council of Professional Technical Education, Uruguay
- VR: Virtual Reality
- WEF: World Economic Forum

Introduction

Smart manufacturing relates to the combination of innovative technologies: advanced software, augmented reality, sensors, big data analytics, robotization and additive manufacturing, that allows new processes, production systems and products. These technologies offer greater flexibility for industrial processes, ease decentralized and autonomous decisions, help manufacture customized products and support the scale of production. These new patterns of innovation in production processes entail many positive externalities for firms. Nevertheless, if appropriate actions are not taken, this new industrial cycle will once again become another missed opportunity for the region's technological development.

The degree of incorporation and diffusion of advanced technologies in the business fabric depends on a set of factors of different nature. These may be associated with the company's own characteristics such as their size, the sector to which they belong, the organizational structure, the human and financial resources they have, the relationship with customers and competitive pressure, among others. Likewise, technological factors affect its adoption due to costs, availability of solutions and standards, among other reasons. The enabling environment is also another crucial element that condition the adoption of smart manufacturing in regard with the availability of skilled labor, incentives for investment and the modernization of rules and regulations to boost innovation, these aspects strongly influence and condition the diffusion and appropriation of technologies in firms (Rovira, Santoreli and Stumpo, 2016).

Besides the challenges ahead the fourth industrial revolution presents an important opportunity for Latin America and the Caribbean. The pandemic brought with it a significant economic and social crisis but also encouraged the adoption of new technologies in various productive activities, accelerating innovation and changing consumption patterns. This stimulus can be used to prompt technological change, but the momentum for the adoption of new industrial technologies will depend on an institutional design that encourage innovation and provides an enabling environment for more technological intensive activities.

The purpose of this study is to analyzed the current state of policies and initiatives around smart manufacturing in Latin America and serve as an inspiration to continue the development of this policies, identifying at the same time the main institutional and coordination problems that hinder technological change. This study is a result of the 2019 annual Cooperation Programme between ECLAC and the Republic of Korea. This, cooperation agreement seeks to strengthen the capacities of policy makers in Latin America and the Caribbean to adequately address the challenges derived from the internationalization of small and medium enterprises, productivity gaps and difficulties for incorporating digitalization in the productive processes, among other relevant issues.

This report has three sections. The first part examines the productivity challenges in Latin America and the Caribbean and its structural characteristics, highlighting the opportunity that new technologies present to overcome those challenges and gaps. The second section presents an analytical framework that seeks to map the elements that influence the adoption of new technologies and practices regarding smart manufacturing. Based on this framework the chapter then examine a set of initiatives and case studies on smart manufacturing both public and private. The last chapter, founded on the cases studies from the previous section, presents an agenda with key elements that should be considered to comprehensively promote smart manufacturing in the region.

I. Smart manufacturing: an engine for reigniting productivity

A. The productivity imperative in Latin America

Latin America and the Caribbean faces a strong challenge to accelerate productivity and generate more and better jobs to promote inclusive development. In recent decades, the region's growth has been below the growth of both emerging and developed economies. This meager performance in terms of growth has been strongly associated with the nature of growth. While in emerging and highly dynamic economies growth has been mainly related to productivity growth associated with the behavior of sectors that demand technology and knowledge, in Latin America and the Caribbean most of the growth has been explained by expansion of the workforce. For example, while in countries such as China or the United States, productivity has contributed to 96% and 64% of growth, respectively, between 2000 and 2019, in Latin America this number falls to just 24% (CBTE, 2020).

Since 2000, Total Factor Productivity (TFP) in the region has been in decline, having one of the worst performances throughout the world and well below the dynamism of other emerging regions. In this sense, the region has not yet been able to ride the two great waves of transformation of productivity: the ICT revolution that began in the 90s and the most recent and incipient "era 4.0". Beyond the last 20 years, the literature finds a strong divergence between the productivity of the region and that of more developed and emerging economies in the last 60 years, which has been particularly accentuated since the 80s (CBTE, 2020).

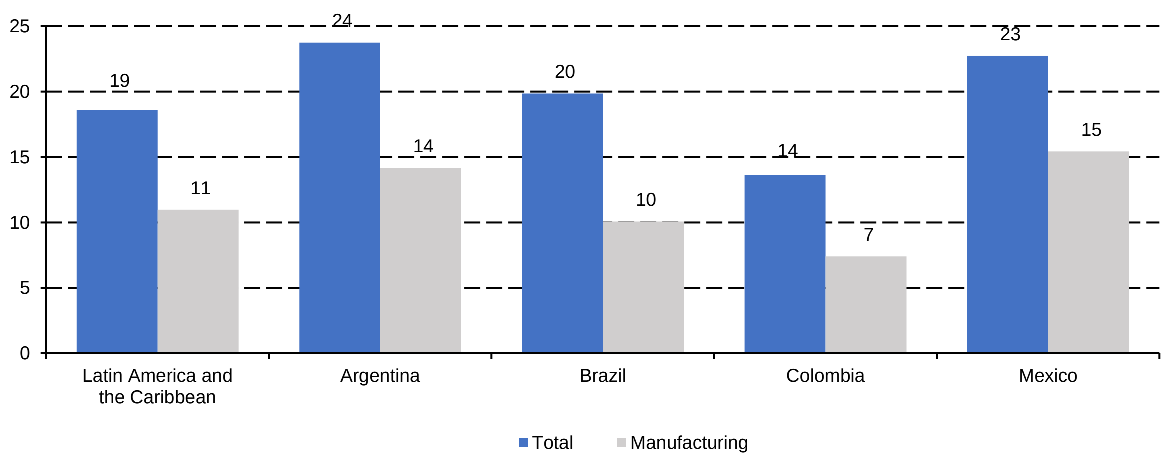
The manufacturing sector is at the heart of this dynamic. Despite signs of premature deindustrialization, manufacturing has remained one of the main employers in the region. Manufacturing concentrates 12.8% of employment in Latin America and the Caribbean and 12.6% of GDP (ILO, 2020). In a country like Mexico, these figures go up to 16.6% and 17.3% respectively, while in Argentina the sector represents 18.7% of GDP (INDEC, 2019) and 18.8% of total employment (UIA, 2021).

Manufacturing also has a key role in flows of trade. Manufacturing concentrates 45.2% of total exports in the region. At the country level, manufacturing captures 80.0% of total exports in Mexico, 31.5% of exports in Brazil and 20.8% of exports in Argentina (INDEC, 2021), for instance. The products with largest export volumes involve mainly computers, televisions and monitors, trucks, and small and medium sized cars.

Yet despite its economic relevance, the region hasn't been able to consolidate a sustained process of industrialization and productive transformation, but rather the opposite. During the last years, the sector has seen little dynamism and showed signs of deindustrialization. Over the last 5 years, manufacturing employment in the region decreased at an annual rate of 0.1% (ILO, 2020).The participation of manufacturing in the region's GDP decreased from 15.8% to 12.6% between 2000 and 2019 (ECLAC, 2021). In Argentina, current activity in the sector is 5% below the levels observed in January 2016 (INDEC, 2021).

As figure 1 shows, productivity levels in the region remain significantly below the average for the aggregate economy. At the regional level, the gap between labor productivity in manufacturing and the average for the economy reaches 69.3%[2] and even goes up to 97.1% in a country like Brazil. There is a significant productivity gap even for Mexico (47.4%), the regional champion in manufacturing.

Figure 1
Latin America and the Caribbean and selected countries: Labor productivity in manufacturing vs. aggregate labor productivity
(Thousand USD per employee, 2019)

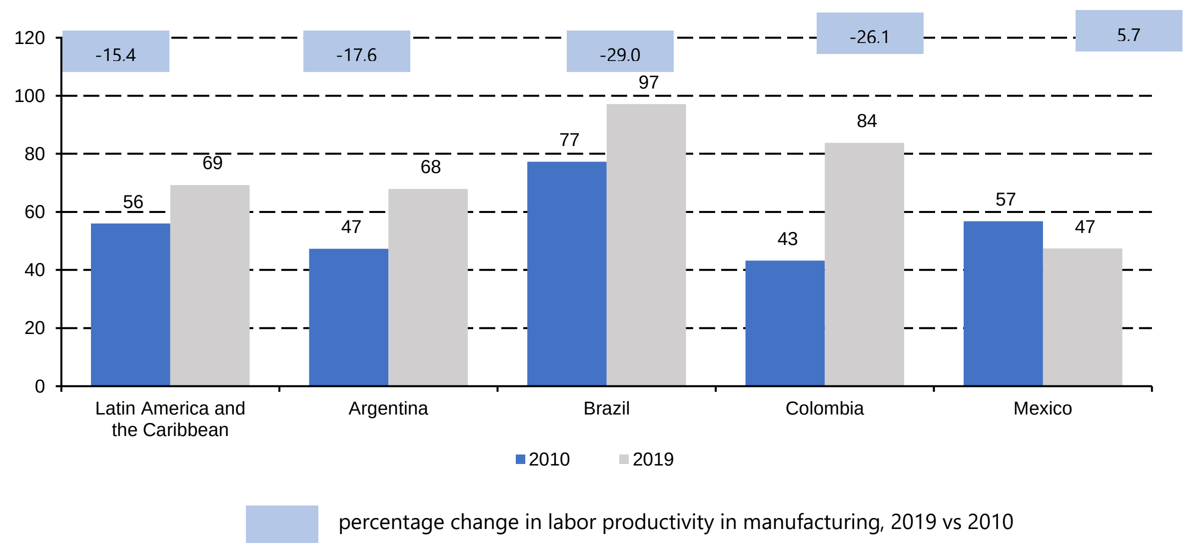


Source: own calculations based on ILO Stats and CEPALSTAT.

It's not just that labor productivity in manufacturing remains low. With the notable exception of Mexico, labor productivity in manufacturing has been decreasing. At the regional level, labor productivity in manufacturing decreased 15.4% compared to levels in 2010. As a result, the gap between manufacturing productivity and aggregate productivity is widening (figure 2). This is also in sharp contrast with global dynamics, as the world level of productivity in manufacturing has been growing at an annual rate of 2.3% between 1992 and 2018. In a country like China, this figure goes up to 9.5% per year.

[2] Calculated as the percentage of labor productivity in manufacturing below the aggregate level for the economy.

Figure 2
Latin America and the Caribbean and selected countries: Gap in labor productivity in manufacturing vs. aggregate labor productivity
(As percentage, 2010-2019)



Source: own calculations based on ILO Stats and CEPALSTAT.

The poor performance in terms of productivity is closely linked to the performance of competitiveness in the sector. The Competitive Industrial Performance (CIP) (UNIDO, 2017) measures competitiveness across 3 dimensions: i) capacity to produce and export manufactures, ii) technological deepening and upgrading, and iii) world impact. According to the CIP, Latin America and the Caribbean is ranked as the least competitive region after Africa.

There are also important differences within the region. Mexico, Brazil, Argentina, and Chile show the best performance, with rankings ranging between 22 (Mexico) and 52 (Chile) out of 150 economies. In sharp contrast, many Caribbean countries such as Haiti, Saint Lucia, or Bahamas show up at the very bottom of the distribution, with CIP ranking between 119 (Bahamas) and 137 (Haiti). Technological deepening and upgrading and world impact play a decisive role in the region: leading economies perform particularly well in this dimension (e.g. Mexico is ranked #17 in terms of technological deepening and upgrading and as #10 in terms of world impact), while laggards perform particularly poorly at them.

In such a context, the adoption of 4.0 technologies becomes a priority to reignite productivity growth and foster the creation of high-quality jobs. Evidence shows most innovative and industrialized economies display significantly higher growth in manufacturing productivity (UNIDO, 2019). While world manufacturing labor productivity grew 2.3% per year between 1992 and 2018, highly industrialized economies saw productivity growth rates of nearly 3.0% per year. China, a frontrunner in advanced technologies, showed even stronger signs of dynamism in manufacturing, with labor productivity growing at 9.5% per year during that same period. Developing and emerging industrial economies (where most countries in the region fit) on the other hand saw productivity growth rates around 2.0%.

At the firm level, digital transformation can impact productivity and growth mainly through 4 main mechanisms:

(i) Lean operations: the digitalization of processes allows optimizing business operations, through both cost reduction and effectiveness improvements. Example: use of 3D printing to produce customized tools at scale.

(ii) Improved decision making: the use of data at scale and advanced analytics algorithms allow optimizing decision making and improving profitability. Example: use of IoT for predictive maintenance of machines.

(iii) Greater connectivity: digital channels and the use of digital marketing and digital procurement tools allow us to expand the consumer portfolio and improve customer acquisition, as well as improve access to suppliers and optimize the supply chain. Example: digital marketplace to connect manufacturing firms to suppliers.

(iv) New business models: the virtualization of goods and services and the digitalization of product delivery encourage the creation of new business models that mitigate risk and improve profits. Example: production of digital twins for testing and simulation.

The emergence and diffusion of advanced technologies is also transforming the nature of manufacturing production, increasingly blurring the boundaries between physical and digital production systems. In this sense, the increasing automation and digitalization of the sector brings important reconfigurations in the value chain. The reversal of offshoring dynamics to give rise to nearshoring and reshoring processes, as well as a growing transfer of value from production to design, R + D + i and services, are mainly highlighted.

For Latin America and the Caribbean, the reshuffling of global flows represents an important opportunity. The shortening of value chains combined with the disruption from the COVID-19 crisis and the intensification of trade wars (mostly between the US and China) opens a significant window of opportunity for regional producers. The US currently imports 429 billion of USD from China (top exports partner), with 91.8% of total imports concentrated in manufactured goods (ICT, 2020).

Beyond increasing production efficiency and reconfiguring value chains, new technologies introduce new goods and services into the market and create new activities, fostering the emergence of new industries and the creation of jobs and income opportunities. Some technologies even help deliver environmental goods and reduce consumption of energy and materials, providing more sustainable production models.

Two key characteristics distinguish smart manufacturing from traditional processes of digitalization: i) the emergence and acceleration of multiple technology domains, including multiple General Purpose Technologies (GPT) and (ii) their complementary in production, which leads to a transformation of production through integrated smart systems (as opposed to the application of specific solutions to digitize isolated parts of the operating model).

UNIDO (2019) identifies four domains that compose the transformation of production along the 4th industrial revolution: new materials, nanotechnologies, biotechnologies, and advanced digital production technologies (ADPs).

ADPs involve some of the digital technologies with highest potential for smart manufacturing, such as: IoT, advanced analytics and artificial intelligence (AI), additive manufacturing, advanced robotics, blockchain, cloud computing, virtual reality (VR) and augmented reality (AR), and autonomous and semi-autonomous navigation (including drones and vehicles), among others.

The effective adoption of ADP technologies requires integrating 3 building blocks: software, hardware, and connectivity. Companies that wish to absorb 4.0 technologies must aim to exploit the data associated with the activities of the production process in a broad sense, within the company and in relations with its suppliers and customers.

Some of the key use cases applications of smart manufacturing technologies are concentrated in real-time monitoring of orders and supplier logistics, virtual development systems, M2M (machine-to-machine) communication, monitoring and management of the customer life cycle and automation of processes of business with artificial intelligence support.

B. The global frontier of smart manufacturing

The global landscape of smart manufacturing reflects high levels of concentration, with ten frontrunner economies accounting for 91% of patents, 70% of exports and 46% of global imports related to advanced technologies in manufacturing (UNIDO, 2020).[3] This group leads not only in terms of creation of new technologies, but also in terms of sales and even adoption. Ordered by their shares, these economies are the United States, Japan, Germany, China, Taiwan Province of China, France, Switzerland, the United Kingdom, the Republic of Korea and the Netherlands.

40 economies follow in terms of engagement in new technologies, but with lower intensity. These economies are salient at some dimension (i.e., production or use), but are unable to succeed across the entire chain of technology engagement. This group includes for instance countries like Israel, Italy, Sweden, or Canada. These economies explain 8% of global patents and almost half of all imports of goods embodying these technologies. The remaining 117 economies comprises late runners and laggards with either low, very low, or no activity in this field.

There is a strong correlation between technology adoption and intensity of manufacturing. 63.2% of value-added in medium-high and high-technology activities is concentrated in industrialized economies, while only 15.3% comes from developing and emerging industrial economies.[4] Conversely, 51.8% of low-technology manufacturing value added is in industrialized economies, while developing and emerging industrial economies contribute with 26.6% of the manufacturing value added.

Highly industrialized economies differ in their strategic approach to smart manufacturing (see Box I). Germany is building on its accumulated technological and industrial capabilities to tackle challenges associated with rising labor and energy costs, infrastructure-modernizing demands and skill shortages (Pfeiffer, 2017). The country's strategy has been characterized as simultaneously defensive, to maintain home-based production and increase flexibility to respond to crises in international markets —and offensive, to retain skills and know-how to support an export-led model (Blanchet et al, 2017).

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3 An important limitation for assessing APD technologies intensity following that approach is that it doesn't properly reflect the role of services, given the lack of availability and granularity of services data in global trade flows.

4 Excluding China.

Box 1
What are the frontrunners doing to promote smart manufacturing?

- In 2015, China and Germany agreed to jointly promote the readiness of their respective economies for smart manufacturing by linking Made in China 2025 and Industrie 4.0 through a memorandum of understanding signed by the China Ministry of Industry and Information Technology (MIIT) and the German Ministry of Economy and Energy.
- The German government began early to create strategic and political initiatives to maintain its leadership mainly in manufacturing activities. These initiatives were institutionalized in the so-called "Industry 4.0 Platform". This platform seeks to promote the adoption of 4.0 technologies among small and medium-sized metalworking companies, a key segment of German competitiveness, through public-private efforts. In 2016, the German government, German industry and science spent a record sum of € 92.2 billion on research and development, equivalent to 2.94 percent of Germany's gross domestic product (GDP). The number of scientific publications per million inhabitants has increased continuously in the last two decades, in 2016 1,367 publications were published per million inhabitants, greater than countries such as the United States or Japan. Global cooperation and collaboration between different sectors also played an important role in this transformation. The German Centers for Science and Innovation (DWIH) bring together the main players in the field of German innovation in the five world megacities: New York, Sao Paulo, Moscow, New Delhi and Tokyo.
- France pursues resurgence through enhanced digitalization and visualization. It also promotes a growing start-up ecosystem to renew the domestic manufacturing base and reposition itself as industry leader, subject to its ability to offset labor costs and related social constraints (Blanchet et al. 2016).
- In Spain, the government of the Basque country launched Basque Industry 4.0, which includes pilot activities to assist domestic SMEs in accessing training on ADP technologies associated with manufacturing, and spaces designed for self- diagnosis and fine-tuning for advanced manufacturing.
- China quickly joined the frontrunners. Whereas highly industrialized economies tend to dominate the frontrunner category, China—a recent graduate to middle-income status—is an exception. It joined the frontrunner group rapidly, steadily changing its approach to industrial development from catching up to capitalizing on its increased ability to (re)produce new advanced technologies, add value and enhance technological content, superseding the traditional cost advantage strategy. China seeks to upgrade within value chains, while exploring new development paths building on decades of systematic and sustained accumulation of technological and productive capabilities.

Source: Adapted mostly from Blanchet, M., Rinn, T., Dujin, A. and Geissler, C. (2016). The Industrie 4.0 Transition Quantified: How the Fourth Industrial Revolution Is Reshuffling the Economic, Social and Industrial Model; Think Act - Beyond Mainstream.

Within countries, technology diffusion is concentrated among a few sectors and firms. In Europe, two industries stand out in terms of adoption of key advanced technologies: i= computers, electronics, and machinery, and ii) transport equipment. The computer and machinery industry has the highest use of cloud computing and 3D printing technologies, at 10–15 percentage points above the average for manufacturing. On the other hand, the transport equipment industry is one of the top performers in terms of cloud computing and 3D printing and is the undisputed leader in industrial robots.

Few firms lead the adoption of advanced technologies, with signs of a strong divide between large firms and SMEs. Large firms tend to develop stronger technological capabilities and have access to larger pools of resources that make them more likely to adopt new technologies. The reverse is true for smaller firms. Studies on technologies associated with the fourth industrial revolution (4IR) among small and medium sized enterprises (SMEs) in Germany and the Republic of Korea suggest that only around 18–20 percent of companies have engaged with them and are familiar with the concept (Sommer, 2015). In Europe, only 6 percent of information and communications technology (ICT) and professional services companies are making strategic and intense use of data, and fewer than 1% of employed personnel are data specialists (European Political Strategy Centre, 2017).

II. The state of smart manufacturing in Latin America

While internet penetration in the region has grown strongly and more than proportionally to income growth, digital adoption in firms has been limited. There are still important gaps in the level of digitalization between the countries of Latin America and the Caribbean and the OECD countries, mainly in terms of digitalization of production processes, digital industries and factors of production, also observing low levels of digitalization of the chain of supply. Although in general more than 90% of the companies along the chain have internet access, low use of electronic payments is observed in some countries (particularly Peru and Ecuador) and low percentages of companies that use digital media to purchase supplies (Gallego, 2015).

Huawei developed an index to measure progress regarding digital transformation across countries. Their Global Connectivity Index (GCI) measures 40 indicators across 2 main dimensions: i) technology enablers (broadband, IoT, cloud computing, and AI) and ii) 4 main pillars of digitalization (supply, demand, experience, and potential). Most Latin American economies lag significantly behind global leaders across most dimensions (Huawei´s GCI, 2020). Chile is the best positioned country overall, ranking 30th out of 79 economies. All other countries in the region fall in the bottom half of the sample. Brazil shows up as the 44th most connected economy, followed by Argentina (50th) and Mexico (53rd). The largest gaps are concentrated in IoT, supply, and demand.

In manufacturing, the digital transformation in Latin America and the Caribbean is still in early stages. According to UNIDO's classification of economies based on adoption of ADP technologies, none of the economies in the region are considered within the 'frontrunners' category, while only 3 countries fall within the 'followers' list (Brazil, Mexico, and Argentina). Most of the countries in the region are considered either latecomers or laggards (UNIDO, 2019).

Within the follower's group in the region, there are significant differences in terms of the profile of the economies. Mexico and Argentina are identified as followers in use. Brazil on the other hand, shows up as the only follower in production in the region. Brazil showcases a set of industrial companies and service providers that constitute the supply of Industry 4.0 digital solutions. Such supply can be classified into 3 main categories: i) large companies that produce enabling technologies, ii) integrating companies, and iii) startups.

Large companies producing enabling technologies (e.g., SIEMENS) offer complete or partial digital systems, including machines, equipment, sensors and software. These companies operate across practically all fields of technologies of Industry 4.0 and have achieved international recognition and experience.

Integrating companies (e.g., Accenture) are mainly focused on software and the automation of specific processes or equipment (e.g. robots). For the most part, they are service providers that make adaptations and customizations in programs or develop programs that integrate parts of the production and management processes of industrial companies. An important difference compared to firms in the first category is the fact that integrators do not produce the technologies.

Finally, startups (e.g. GoEpik) usually showcase technical competence around the development of partial and very specific solutions, involving either digitizing production processes or product controls. This segment has seen particular dynamism in Brazil over the last years. The diffusion of business opportunities, the difficulties in placing trained people in the job market and the nationwide effort to promote and foster startups are some of the factors that have contributed to the growth in this sector (CNI, 2017).

In terms of adoption, evidence shows that advanced digital technologies are still marginally used by countries in the region. In Brazil, one-third of the firms use either third generation or fourth generation technologies; in Argentina, around 20% of firms do. Only 3.7% of Brazilian firms and 2.9% of Argentine firms have adopted the most advanced DTs (Kupfer et. al, 2019). Brazil is also home to the only 2 locations in the region that are part of WEF's Global Lighthouse Network (see Box II).

The areas where there is less progress in terms of the use of state-of-the-art technologies in Argentina are production processes, product development and supplier relations, while in Brazil they are customer relations and business management.

A survey across large firms in Colombia suggests emerging technologies with highest levels of adoption include cloud computing (71.8% of adoption), BI (57%), data analytics (49.1%) and robotics and automation (41.8%) (ANDI, 2019). In Brazil, the leading applications of advanced technologies involve digital automation combined with sensors for process control (46% of adoption), integrated engineering systems for product development and manufacturing (37%), and digital automation with no sensors for manufacturing and business management (CNI, 2018).

Mexico shows one of the strongest performances in terms of adoption of ADP technologies. Mexico shows up as the country in the region with the highest potential in terms of implementation of industry 4.0 technologies and is also ranked 22nd globally in terms of productive structure (Americas Sustainable Development Foundation, 2020). Advanced technologies explain 40% of value added in manufacturing in Mexico. In sharp contrast, high-tech represents only 13.7% of value added in manufacturing in Chile, underperforming compared to countries like Mexico, Brazil, Colombia, and even Uruguay.

Box 2
Smart Factories in Latin America and the Caribbean

In 2018, WEF and McKinsey & Company started recognizing global leaders in advanced manufacturing as part of a "Global Lighthouse Network". According to their definition, Lighthouses succeed "by innovating new operating systems, including in how they manage and optimize business and processes, transforming the way people work and use technology". As of today, only 2 sites in the region out of 69 lighthouses in the global network were able to achieve that recognition: Renault Curitiba and MODEC in Rio de Janeiro.

Renault Group (Curitiba, Brazil): approached APD technologies by focusing on improving employee accountability and E2E connectivity, engaging its workforce and developing a connected ecosystem across value-chain players including dealers, customers and workers. Key use cases include improving customer connectivity through B2C e-commerce platform (increased 10% sales of selected models), improved connectivity among workforce (decreased 19% of non-value-added activities), and flexible automation through AGVs and cobots (reduced 10% cost per unit).

MODEC (Rio de Janeiro, Brazil): transformation towards smart production focused on leveraging advanced analytics for predictive maintenance, developing a digital twin of the process plant, and developing a proprietary data platform to accelerate development and enable exponential scale-up of new algorithms across oil production vessels. Key use cases include developing a digital twin (improved 65% downtime in first year of operation), AI to accelerate scaling of digital applications across fleet (60X in productivity) and launching a digitally enabled people performance management system (improved 20% organization health).

Source: Adapted from World Economic Forum and McKinsey & Company, Global Lighthouse Network project, white papers in 2020 and 2021.

Most firms in the region are still heavily dependent on first- and second-generation technologies. In Argentina, 86% of the firms use, on average, first- and second-generation technologies. In contrast, in Brazil that average falls to 78% (Albrieu et. al, 2019).

The adoption of advanced technologies has been highly limited and uneven across businesses. While some firms have managed to capture much of the benefits of digital technologies, there is a long line of digital laggards made up mainly of SMEs and businesses in traditional and vulnerable activities, typically associated with lower levels of productivity and greater informality.

First, there are important differences in digitalization across sectors. Sectors such as financial services and the ICT sector typically appear as activities with the highest level of digitalization both in the region and in other countries around the world. At the other extreme there are sectors with greater digital lags, such as agriculture, real estate services or education. Manufacturing lies somewhere in the middle. A survey in Colombia reveals that, while 63.5% of the companies have a digital transformation strategy, the figure goes down to 54.9% for manufacturing (ANDI, 2019).

There are also strong levels of heterogeneity within manufacturing activities. In Argentina, while activities such as biopharmaceuticals and automobiles show higher levels of digitalization, activities such as agricultural machinery, food or the textile industry show up as technological laggards. In Brazil, manufacturing activities with highest innovation rates involve extractive industries, electrical equipment, cell phones, and food products (CNI, 2017). The opposite side of the distribution comprises activities such as wood, leather products, textiles, or paper products.

In Mexico, 3 types of sectors are identified in terms of their engagement with advanced technologies: i) mature sectors, such as textiles, shoes, metalworking, wood, food, drinks, etc., ii) dynamic sectors, such as automotive, auto parts, aerospace, electronics, and chemicals, and iii) emerging sectors, such as biotech, pharmaceuticals, IT, creative industries, and medical equipment (Americas Sustainable Development Foundation, 2020). In Chile, industry 4.0 is seeing significant progress not only in traditional manufacturing activities such as food, but also in associated services such as automotive maintenance (El Dinamo, 2019).

The impacts associated with 4.0 technologies will not reach every industry by the same extent nor at the same time. Multiple digitalization paths arise based on the nature of products and processes (CNI, 2017). For instance, businesses with traditional products and conventional processes may seek to adopt a strategy to transform processes and then shift to advanced products. In the textile industry, beyond the revolution in production, new materials have allowed incorporating technological components into clothing, potentially making traditional products obsolete. In such cases, the mere digitalization of production is not sufficient to ensure long-term competitiveness. Conversely, for companies producing goods that are already technology intensive the path towards digitalization may be decisive.

There is also significant heterogeneity at the firm level. The impact of advanced technology will vary depending on the technologies adopted, the degree of integration, and the business strategy. The transformation of production has a significant impact on the internal structure of companies and will require for instance greater flexibility and cooperation across areas. Companies will also need to develop and evolve their business models, particularly in terms of how they interact with suppliers and customers.

Scale seems to play a decisive role in that sense. While only 10% of large firms in Argentina rely on first generation technologies, the figure goes up to 45% when considering small firms (Kupfer et. al, 2019). In sharp contrast, while 34.2% of large firms state that they are already using third generation technologies, only 12.0% of small firms fall in that same category. The divide remains and is even intensified when considering most advanced technologies, with 7.9% of large companies being adopters versus merely 1.5% for small firms.

Low and medium low technology firms in Brazil seem to be farther ahead than their counterparts in Argentina. While the share of high-technology and medium-high technology firms adopting third generation technologies is similar in both countries (28% vs. 26%), there are significant differences in low and medium-low technology intensive firms. In Argentina, a significant amount (43.9%) of low and medium-low technology firms have adopted first generation technologies and only 6.6% use third generation technologies. In Brazil, one third of firms in the low- and medium-low technology group use first generation technologies, while 23% adopted third generation technologies (Kupfer et. al, 2019).

There is a positive correlation between adoption of latest technologies and access to global markets. In Argentina, 61% of manufacturing firms leading the adoption of advanced technologies are exporters, while only 23% of laggards do so (Albreiu et. al, 2019).

Multiple constraints inhibit the flourishing of smart manufacturing technologies. A regional study (Americas Sustainable Development Foundation, 2020) covering Brazil, Mexico, Colombia, and Chile identifies six main barriers for the adoption of 4.0 technologies in manufacturing: high amount of investment required, lack of clarity on ROI, lack of appropriate culture, difficulties for integrating new software into existing systems, lack adequate IT infrastructure, and lack of access to financial resources.

In Argentina, lack of access to financing shows up as the main binding constraint for adopting advanced technologies in the manufacturing sector (Albrieu, 2019). There are also firm-specific obstacles associated with digital maturity. 40% of digital leaders consider inadequate digital infrastructure a key obstacle. For digital followers, the main factors inhibiting the adoption of new technologies are culture (12% of manufacturing firms), lack of awareness (7.5%), very long terms to amortize the investment (close to 10%) and lack of appropriate talent (about 10%). Finally, among digital laggard's lack of adequate talent arises as a top concern (14%), together with excessively long periods to amortize the investment (6%).

A survey by the Union Industrial Argentina (UIA) suggests the role of awareness may be understated, as many firms fail to recognize their lack of awareness - i.e., "they don't know that they don't know". When asked about specific technologies, many manufacturing firms recognize they are not aware of their existence. For instance, 31.7% of manufacturing firms are not aware of nanotechnology solutions, while 24.1% of them state they are not aware of process sensing technologies and 23.5% fail to recognize digital manufacturing simulations (UIA, 2020) .

Lack of adequate access to providers of 4.0 solutions may play an important role as well. Only 21.3% of manufacturing firms in Argentina believe it's easy to find an adequate provider of advanced technology solutions. There also seems to be significant path dependence around the supplier's network, as only 32.8% of firms work with 4.0 providers they didn't know or hadn't heard of before (UIA, 2020).

For Colombian firms, four obstacles arise as main inhibitors of the digital transformation: lack of financial resources (59.2%), lack of proper culture (57.1%), lack of awareness (55.4%), and lack of a clear business model (36.5%) and 41.6% of firms state they do not know emerging technologies. Even within adopters there are important difficulties for advancing with the digital transformation. 64.3% of companies in Colombia do not quantify the impact of investments in digital technologies (ANDI, 2019).

Despite the bittersweet present, expectations about the future remain optimistic. In Argentina and Brazil, the percentage of firms that expect to use third and fourth generation technologies over the following 10 years is twice as much as current levels (across all functional areas) (Albrieu et. al, 2019). In terms of priorities among mature technologies, manufacturing companies highlight e-commerce (81.7%), collaborative platforms (78%), and digital marketing (72.5%).

Yet investments in advanced technologies seem to amplify the preexisting digital divide among firms. In Brazil, 96% of firms that intend to invest in 4.0 technologies already adopted at least one emerging technology, while only 7% of firms that haven't adopted any emerging technology are planning to invest (CNI, 2018). In terms of objectives, priorities for investments involve the introduction of new production processes (71%), improvement of the current production process (65%) and the introduction of new products (64%).

While both investing firms and non-investors identify increased demand as a key driver of investment decisions (69% of investors and 61% of non-investors identify it as a stimulating factor), technical capabilities have a more divisive role (CNI, 2018). 53% of investors see technical factors as a stimulating driver, while only 36% of non-investors do (with 42% stating it has no influence and 20% seeing it as a limiting factor). Financial resources and regulation are seen as inhibiting factors for the majority of investing and non-investing firms.

Beyond expectations about the future, there are important challenges in terms of materializing them into concrete actions. More than 60% of firms in Argentina and Brazil say they are not taking any action regarding the adoption of these new technologies. There are also important differences in terms of the proportion of firms taking concrete actions to get closer to 4.0 technologies. The percentage of firms that are taking them is three times higher in Brazil than in Argentina, when the average of the functional areas is considered (Albrieu et. al, 2019).

Investments in improving technology are linked to activities such as R&D, investment in fixed capital and contracting of companies specialized in digital technologies. It is not surprising that the most advanced companies are the ones that invest the most in improving their technologies. 3 out of 4 companies among the digital leaders hire specialized companies while only 21% and 8% of the companies in the followers and laggards' groups do so respectively.

In Colombia, 66.5% of the companies stated they made investments on digital technologies in 2018 (ANDI, 2019). The top goals behind those investments were: process automation (91.1%), cost reduction (57.3%), and gaining online presence (39.5%), among others. For manufacturing firms, the share of companies investing in emerging technologies is 54.9% (compared to 70% in the services sector). Main applications involve process automation (81.4%), cost reduction (53.1%), disrupting their own industry (43.4%), and creating additional sources of income (33.1%), among others.

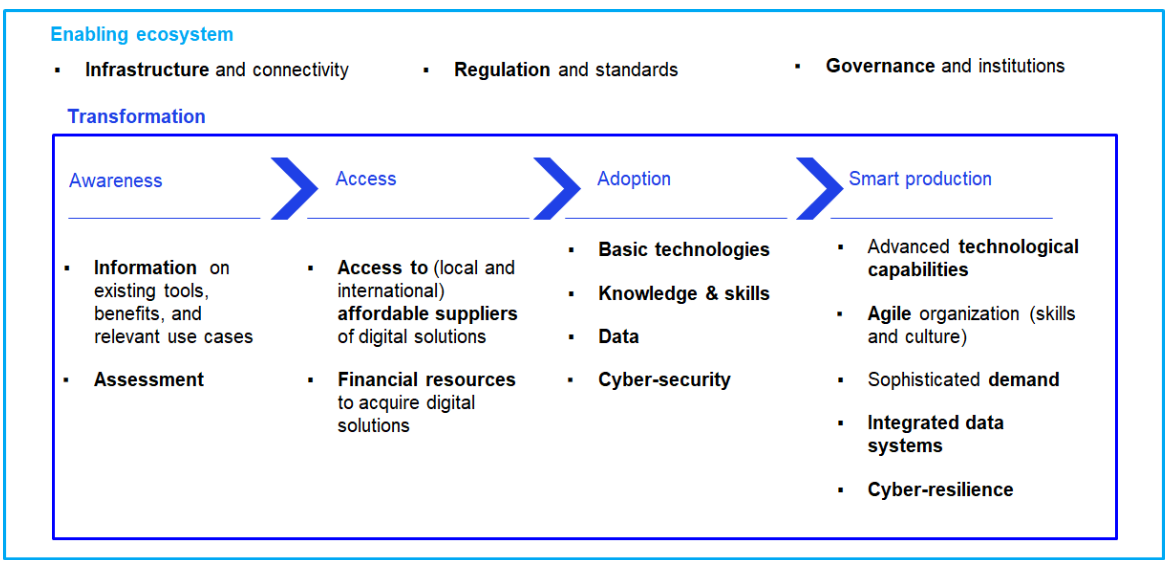
A. Smart manufacturing in Latin America: Analysis framework and case studies

Following the experience that the developed nations have had since the late 2000s and early 2010s, Latin American countries have started recently deploying strategies and interventions aimed at promoting the smart transformation of manufacturing and the local development of smart manufacturing solutions. In this chapter, we explore and characterize distinguished examples of initiatives aimed at promoting smart manufacturing across the region. Such initiatives involve not only examples of public policy, but also public-private efforts and private projects. For each case a detailed description is provided of the salient characteristics of their design, to offer a useful reference for policy design.

Interventions are structure among two main pillars: enabling ecosystem and transformation. Enabling ecosystem refers to systemic aspects that are external to the firm that condition the behavior and act as a prerequisite for adopting technological solutions. It entails mostly actions related to infrastructure and connectivity, regulation and standards, and governance and institutions (see diagram 1).

Transformation refers to those initiatives that have a direct effect on business behavior and that contribute to facilitate the path towards smart manufacturing. The transformation encompasses 4 main stages: awareness, access, adoption, and smart production.

Diagram 1
Enabling ecosystem



Source: own elaboration.

1. Enabling ecosystem

Infrastructure, connectivity, regulation and standards

The transformation that companies must undertake to adapt and take advantage of smart manufacturing technologies requires a broad set of efforts and investments. Such efforts require a range of conditions that are not determined at the firm level. Access to connectivity infrastructure and the definition of rules that include, but are not limited to, technical standards, cybersecurity, data privacy, digital trade, and AI, are key elements of information governance for smart manufacturing. For example, smart manufacturing cannot take place without technological standards for information flows within a company and across its supplier chain, this specification for materials, products, processes, or services are key to allow communication between machines, systems, hardware, and software. Also, smart manufacturing relies on highly integrated value chains and management of personal information, which raises the stakes for cybersecurity and data protection rules. Digital trade disputes could be also consequential for services, platforms and applications that enable smart manufacturing. New norms for technologies such as Artificial Intelligence (AI) (via regulation or standards or other means) will impact also smart manufacturing. These components could shape the opportunities for smart manufacturing and the advent of the Industrial Internet of Things (Belton et. al, 2019).

Regarding connectivity the deployment of fifth generation mobile networks (5G) is a disruptive process for the industrial organization and manufacturing models due to some capabilities such as higher transmission speeds (up to 20 gbps), low ultra-reliable latency (less than 1 millisecond), higher network security, strong communication among equipment and the energy efficiency of devices. The use of these networks will allow the development of wireless broadband services with low latency and reliability to support key applications and innovative uses in practically all industries (ECLAC, 2021).

In recent years, some countries in the region have undertaken reforms to the regulatory frameworks of their telecommunications markets in order to facilitate and promote investments that extend Internet access to broader geographies (which is particularly relevant for value chains outside the main industrial belts) and set the ground for the landing of 5G technology. Colombia for instance sanctioned the Law of Market Modernization (Law 1978) in 2019 as part of their ICT Law effort and building on the success of the previous Plan Vive Digital.[5] Such effort was complemented with auction mechanisms and initiatives such as "Hogares Conectados" and "Centros Digitales", which aim at reducing the digital gap by bringing Internet access to rural areas and the most neglected social sectors. Despite the momentum, progress around "last mile" connectivity has been limited and focused purely on households. Among the reforms introduced, the Law extended the term of radioelectric space use permits, facilitated their renewal, and created a single regulatory entity.

Brazil sanctioned law 13,879 in 2019, which enables the National Telecommunications Agency (ANATEL) to transform fixed telephony concessions into authorizations, making the universalization obligations of this service more flexible in exchange for investment commitments in broadband services.

Chile was the first country in the region to launch 5G spectrum tenders. The 5G standard would have a significant impact on the possibility of harnessing the potential of 4.0 technologies. It would allow to provide high transmission speeds and reduce the risks of bottlenecks when transmitting a large amount of data, something that becomes even more relevant in the context of transferring information to the Cloud; 5G will also offer low latency connections, a critical aspect for an environment dominated by Machine-to-Machine interaction, among other aspects that also include raising cybersecurity parameters (Corrada, 2020). The bidding's results in Chile showed a 453 million dollars take, well above the values corresponding to previous bids; and established a maximum period of 3 years to start operations. The estimated investments for the next 5 years are around 4 billion dollars (Gobierno de Chile, 2020).

Countries such as Argentina, Brazil, Colombia, Costa Rica, Mexico and Uruguay, have begun carrying out technical tests in recent months and are navigating different stages of the pre-bidding period, which is expected to take place during this year or 2022. Some of the aspects at the core of the current discussion involve the alternatives of a single network used by different operators, a "pure" 5G network (that is, without considering the pre-existing 4G infrastructure), and an exclusive network for government agencies.

[5] Which focused mostly on strengthening geographic connectivity.

Governance and institutions

Public policies to promote smart manufacturing cover a wide range of initiatives, which involve coordinating many actors both around systemic aspects -external to the firm- and those that directly affect business behavior. The complexity of the challenge therefore requires institutional mechanisms that contribute to the coordination of actions, in such a way that together they mean the implementation of a coherent strategy and avoid unnecessary overlaps, contradictory signals or inappropriate sequences that reduce the return on public and private investments.

A key issue regarding smart manufacturing policymaking is technology diffusion. As mention before, in Latin America and the Caribbean this concern is aggravated due to structural heterogeneity. One key aspect is improving scientific and technological based ventures with innovative value propositions and high probability of success. Another issue is to increase technology adoption in established companies facing some type of restrictions (e.g. SMEs). These concerns involve different policy instruments therefore a coherent approach is required.

A large group of countries in Latin America and the Caribbean already have digital agendas at national level, nevertheless these instruments still lack certain design characteristics that are necessary to ensure their results, such as an entity in charge of leading the digital agenda with and adequate level of hierarchy, an explicit budget and institutional mechanisms for coordination with the private sector. Also, specific strategic instruments are needed to guide the digital transformation of the productive sector and the adoption of emerging technologies. However, some countries are starting to lead some initiatives like, Brazil with the National Plan for the Internet of Things, Colombia with the Center for the Fourth Industrial Revolution, and Uruguay with the Digital Manufacturing Laboratory (CEPAL et. al, 2020).

2.Transformation

Awareness

The first challenge faced by initiatives aimed at promoting smart manufacturing is the degree of sensitivity to that agenda by incumbent actors. The macroeconomic instability across the region combined with the drop in demand experienced in recent years threaten longer term investments. Moreover, the low insertion in global value chains reinforces the perception that the 4.0 transformation represents a distant "developed world" problem or limited to the business elite.

Companies that intend to begin their transformation process, in particular SMEs, tend to lack the information and knowledge that is required to identify their needs and opportunities, as well as to measure the impact of new technologies. This inhibits both an adequate optimization of the investment portfolio and the capacity to evaluate suppliers.

In response, various countries in the region started implementing different initiatives aimed at raising awareness on the potential of smart manufacturing solutions and its relevant applications. In addition to conferences and seminars, one of the most widespread forms of intervention is the provision of self-diagnostic tools, which allow companies to have a first characterization of their situation at a very low cost and benchmark their performance against peers. Examples of this approach involve the SENAI 4.0 self-diagnosis tool (which acts as entry point for the program, described in detail later) and Argentina's tool designed under the framework of INDTech 4.0, a public-private initiative that acts as a collaborative hub for the smart transformation of manufacturing SMEs. A similar effort involves IADB's "Chequeo Digital" (digital assessment) tool, which has already been implemented in Chile across more than 4,000 firms. Despite the similarities, this tool is more focused on service SMEs rather than on manufacturers, which represent a small percentage of the cases.

Demonstration factories show a variety of new digital technologies in simulated production processes. They are inspired in Germany's Mittelstand 4.0 Competence Centers and demonstration fields usually part of agricultural extension strategies. These facilities tend to showcase a broad set of technologies and are mostly focused on making the effects of technology more tangible for non-adopters.

Access

Access to new technologies and solutions is a basic precondition for the smart transformation of manufacturing companies. This requires the existence of solution suppliers (either local or global), information on their existence and knowledge on their quality of service, and, finally, the economic and financial capability to afford the solution.

Initiatives that aim at strengthening the portfolio of local solutions are focused both on supporting innovation projects and on promoting the scaling of start-ups. A good example of the former is represented by the recent call by the Funding Authority for Studies and Projects (FINEP) in Brazil for innovation projects specifically focused on the axes of Industry 4.0, Agro 4.0, Health 4.0 and Smart Cities. The call was for projects between USD 100 000 and USD 1 million approximately, for a total budget of USD 10 million. 1.190 proposals were received, of which 309 were considered meritorious and 26 of them financed. Almost 90% of the approved proposals came from SMEs and 74% included an association with an entity of the scientific-technological subsystem. Artificial Intelligence, Cloud Computing and IoT were among the leading enabling technologies in final projects, while Advanced Robotics had less prominence.

Another example in this direction is the program "Producción Colaborativa" (collaborative production), run by the Ministry of Industrial Development of Argentina. The program pursues the development of partnerships either among companies or between companies and universities or technological centers, where each partner must have expertise in at least one of the activities that is prioritized by the previous Ley de Economía del Conocimiento (Knowledge-based economy law). This law was approved last year once the previous Software Law came to an end and it considers a wider spectrum of activities that can apply for tax reductions, among which it includes the production of technologies for Industry 4.0. Producción Colaborativa offers subsidized loans for innovative projects for up to approximately USD 1 million. Its first call received 45 proposals, 17 of which involved at least one partner that uses or expects to use one of the following technologies: 3D printing, AR, robotics and process automation.

Traditional initiatives typically include the creation of online platforms that act as a digital provider's catalogue or B2B marketplaces. More innovative approaches involve for instance the development of instruments and talent focused on services provision, such as tech integrators. Tech integrators are intermediary agents that play a critical role for the process of diffusion of new technologies, as service centers and contractors do in the agricultural sector (Lodola, 2008). They manage a wide range of technological options, keep up to date on the available alternatives and customize the implementation plan to the needs of adopting companies.

The economic and financial conditions to access both new technologies and the services of these intermediary agents can become a significant barrier to entry. Brazil's BNDES launched two credit lines with the objective of adopting technologies related to Industry 4.0: Finame Máquinas 4.011 and Serviços 4.0. Finame Máquinas 4.0 provides financing for the acquisition of machines and equipment with 4.0 technology. This program is in operation with a set of accredited products. FINAME Serviços 4.0, in turn, aims to finance technological solutions with 4.0 technologies and is open for the accreditation of services by supplier companies. Beyond the traditional investment subsidy schemes, innovative alternatives, adjusted to the specific characteristics of the new technologies, can be explored. An example of this is the commercial innovation that the subsidiaries of Siemens have implemented, transforming software like their Manufacturing Execution System from a software as a product approach to a software as a service one.

Adoption

The transformation towards smart manufacturing tends to be conceived in the early stages as a process of technological modernization. At this stage, the actions that companies must undertake are less specific, and tend to demand an upgrading in the organization of production processes, as well as the incorporation of non-customized technologies and skills. In this sense, initiatives that facilitate training and access to knowledge outside the firm are critical.

The design of processes that maximize the returns on investment becomes more relevant. This requires segmenting the needs of different companies in order to allocate resources accordingly. Self-diagnostics and more in-depth diagnostics are tools that allow to increase outreach at a low cost and contribute significantly to the segmentation process. The development of action plans that enable a smart sequencing of investments is also critical. This implies not only favoring a better use of technologies and, therefore, of the resources invested, but also a growing conviction of decision makers about the transformation they are undertaking.

To this end, several countries are beginning to use a self-diagnosis tool that was financed by the IADB (Chequeo Digital). For instance, Chile intends to use it to guide its training offerings, while Costa Rica is planning to complement it with an assistance program pilot targeting 100 companies. In Argentina, theNational Institute of Industrial Technology INTI (Instituto Nacional de Tecnología Industrial) is implementing a pilot project for the diagnosis and preparation of action plans for companies belonging to selected industrial activities.

Beyond diagnostic tools, different countries have created new centers or strengthened existing ones in order to train new generations of industrial workers and train current ones in the handling of new technologies. Such initiatives encompass both public efforts and joint ventures between the public and the private sector. Such is the case of Colombia's national training service, SENA (Servicio Nacional de Aprendizaje). Through a strategic partnership with SIEMENS, SENA created the Didactic Factory 4.0, located in the Center for Design and Metrology in Bogotá. Similar efforts take place in Mexico, where a network of industrial innovation centers financed by PROSOFT seek to combine training facilities with technical assistance capabilities.

Smart Production

The transformation towards smart production goes way beyond the adoption of technological solutions along the operating process. Becoming a 4.0 firm requires a significant shift in the set of skills that the company requires, as well as adjustments in its organizational structure and culture. The greater relevance of integrated data systems and the transformation of the factory into a cyber-physical space emphasize the importance of cybersecurity across the entire firm, both internally and also regarding its interaction with suppliers and customers.

Such transformation entails also significant investments in more customized technological solutions. This generally requires a higher level of intensity in technological development efforts and open innovation strategies with start-ups and institutions in the scientific-technological ecosystem.

Is necessary to acknowledge that the case of the level of adoption of 4.0 technologies in relation to most firms in Latin America respond in part to natural competitiveness strategies of certain sectors and to the certain obstacles. Nevertheless, the adoption of 4.0 technologies seems to be more than a binary reality. In most cases, and especially among SMEs partial adoption is the norm, even it seems that this is also to be true for manufacturing companies as well. Even though this is far from the ideal automated factory, the objective of policies should recognize that the gradual adoption of these technologies is more common among firms (Albrieu, et al., 2019; Motta et al., 2019).

To provide information on possibilities, conflicts and principles which may assist shape and support policies in this area, a set of activities connected to the promotion of smart manufacturing are reviewed below.

B. Nuevo Leon 4.0 (Mexico)

Outreach: Sub regional.

Type of initiative: Public-private.

Leading organization: Secretary of Economy and Labor and Private Sector.

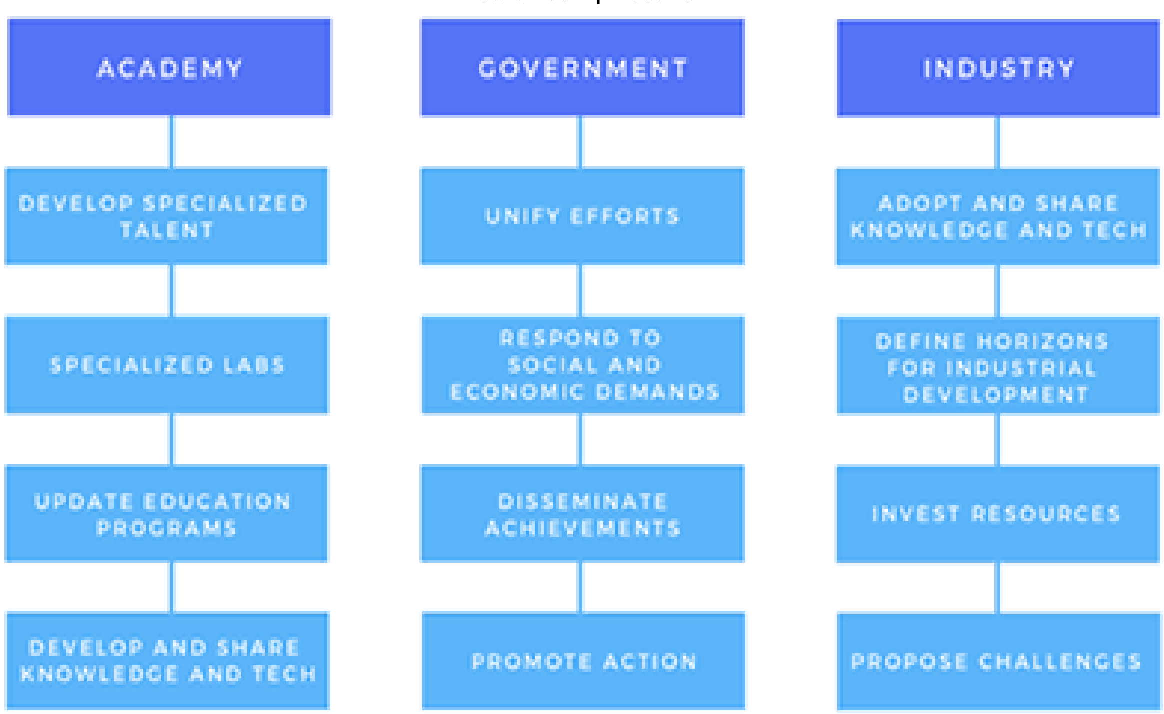
Description: Institutional organization for identifying priorities and coordinating actions to promote Smart Manufacturing.

Key dimension/s: Governance.

The Nuevo León 4.0 council (NL4.0) was launched in 2017 as a private-led initiative building on the state council for strategic planning, whose economic development commission is today chaired by one of the industry representatives in the governing body of the NL4.0. This initiative embodies an institutional model designed to coordinate the actions of the different actors around the Industry 4.0 ecosystem.

NL4.0 has a governing council composed of state authorities, representatives of the National Council for Science and Technology (Conacyt), businessmen, and the authorities of the main local universities. The work is organized around 9 working groups, in which expert researchers, industrial technologists, representatives of clusters and technicians from the state and federal governments participate.

Diagram 2
Nuevo Leon 4.0 Council



Source: Own elaboration based on Nuevo Leon 4.0 Council.

The groups are structured around the following themes: humanist ethics, public policy, talent development, strategic alliances, technological infrastructure, new business models, proactive collaboration, invite to action, and communications architecture. The public policy working group for instance focuses on identifying and removing legal and administrative barriers that hinder technological transformation, while the strategic alliances task force aims at negotiating favorable access conditions with global solutions suppliers.

The strategy carried out by NL4.0 has materialized into a set of actions and programs with public and private funding. These actions and programs include raise awareness initiatives for employers and workers around 4.0 solutions, design and implementation of new training programs and facilities, technical assistance for industrial transformation 4.0, innovation centers, or start-up acceleration to provide a few examples.

Awareness-raising actions involves events and platforms for the dissemination of technology use cases and success stories, symposiums with union leaders, and the Tecnos 4.0 award - financed by the Ministry of Economy and Labor, aimed at the recognition of small, medium and large 4.0 solutions.[6] One of the most salient initiatives around talent development involves a joint effort between the State Ministry of Economy and Labor and the German company Festo. The initiative aims at training 4,000 students (at a technical level) and 600 teachers in industry 4.0 issues and will require an investment of 6 million euros. The approach is highly interactive and relies on the use of games for teaching skills.

Apostoles 4.0 supports the journey of SMEs with smart manufacturing transformation. The technical assistance characterizes and prioritizes problems faced by small and medium manufacturing firms and subsequently helps identifying and co-creating solutions. NL 4.0 also includes the coordination of a network of innovation centers located in the universities that participate in the council. These innovation centers are specialized in core 4.0 technologies, such as Machine Learning and Artificial Intelligence. Finally, MIND 4.0[7] is an industrial accelerator program that fosters the access to innovative solutions through linking start-ups with the needs of large manufacturing companies.

C. Buenos Aires Industry Innovation Center "Centro Industria X" (Argentina)

Outreach: National.

Type of initiative: Private.

Leading organization: UIA and Accenture.

Description: Innovation Center that works as a showroom for new technologies and provides information, training and technical assistance.

Key dimension/s: Awareness – Adoption.

Centro Industria X, inaugurated at the end of 2020, is the result of an alliance between Argentina's manufacturing association UIA (Unión Industrial Argentina) and the local Accenture subsidiary. The initiative was the result of a diagnostic which identified low levels of integration between manufacturing and technological services in the country. In 2018, UIA participated in a study financed by IADB that carried out a survey to more than 300 industrial firms to know about the adoption of smart technologies and their business model.

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6 Both implemented and in development stage.

7 Inspired by Pais Basque's BIND 4.0 initiative.

The Buenos Aires center joins a network of 15 Industry X innovation centers worldwide. The Industry X Innovation Network is led by a US firm which recently acquired Pollux[8] and Wolox.[9] The Buenos Aires Center is the first of its class in Latin America and the Caribbean and the first one where a business union plays a leading role in terms of governance. The Center is located on the 3rd floor of UIA's building and the association not only covers the use and maintenance of the spaces but also part of the management team, with a General Manager appointed by Accenture and a project leader chosen by UIA.

The initiative aims at facilitating the absorption of emerging technologies and supporting the digital transformation process by providing firms information, training, and technical assistance. The Center allows them to experience demonstrations effects on the potential of new technologies, involving for instance complete automation solutions, the simulation of cyber-attacks and possible mitigation strategies, video analytics and facial recognition, and even the use of digital twins to provide real time predictive visibility on operational performance in order to identify potential risks and design recommendations. The tour is guided by Accenture specialists with experience in the implementation of transformation projects and by personnel provided by UIA.

The physical demonstration circuit is complemented with other awareness-raising actions, such as a series of seminars aimed, for example, at presenting success stories on the adoption of different technologies or introducing technical schoolteachers to the characteristics and potential of new technologies.

The Center aspires to become a collaborative space to facilitate the transformation journey for SMEs and provide a platform for linking the demand and supply of solutions and forming a network of experts in smart manufacturing that can provide technological concierge services.

The initiative required an investment of USD 500,000 to adapt the facilities and incorporate the necessary equipment, which includes a variety of software, sensors and VR and AR devices, among others. Accenture absorbed this investment on top of supplying the adequate talent to guide the demonstrations and train UIA's facilitators for this purpose. UIA, for its part, provides the physical space, finances operating costs and, especially, offers capillarity and access to manufacturing companies through its network of associated entities.

D. Manufactura Cohesiva (Colombia)

Outreach: Global.

Type of initiative: Private.

Leading organization: Manufactura cohesiva.

Description: Software start-up.

Key dimension/s: Access.

Manufactura Cohesiva (which translates to cohesive manufacturing) is a Colombian start-up that was born in 2019, with the support of Ruta N from Medellín. Its goal is the development of technology engines (cloud and web) for the specification, execution and friendly monitoring of manufacturing jobs. Based on three-dimensional environments and the ability to interact in real time, the company allows manufacturing companies to raise their needs in terms of machining, forging, electro-eroding and 3D printing. The platform enables sharing technical design details and receiving offers from potential suppliers. At the same time, the software functions as an environment for collaborative design between different companies and induces the optimization of idle capacity at the provider level.

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8 A Brazilian company with a regional presence that provides industrial robotics and automation solutions.

9 An Argentine company specialized in cloud-based solutions.

In its initial business model, the company acted as an intermediary by curating orders through its own administrators and sharing them with a network of suppliers. Quotes were provided to potential customers anonymously. Through this model, 5 manufacturing companies were linked with 20 suppliers and 80 transactions were carried out. This initial approach showcased the value of having a software to generate a qualified technical interaction, as well as a platform for information sharing, particularly for companies located outside the most industrialized regions, which lack adequate access to competitive suppliers. But at the same time this experience illustrated the limits that a market with a relatively small number of players poses to schemes that try to use a monetization scheme based mostly on intermediation. That eventually led the firm to redesign its business model and focus on capturing value through a subscription scheme that provides access to the use of the software and enables an adequate interaction between clients and providers.

E. Innovacred 4.0 (Brazil)

Outreach: National.

Type of initiative: Public.

Leading organization: FINEP - Ministry of Science, Technology, Innovation and Communications.

Description: Financial support for the development and implementation of an action plan that involves the use of services for the adoption of smart technologies.

Key dimension/s: Access – Adoption.

Brazil's national manufacturing association, CNI (Confederação Nacional da Indústria) carried out in 2017 an analysis of the supply structure of the enabling technologies of Industry 4.0. The diagnostic pointed out that the *integrating companies* were critical agents for the dissemination of these technologies. While SENAI (Serviço Nacional de Aprendizagem Industrial) assists SMEs in the first stages of the digital transformation path, integrating firms would help medium and large companies advance towards the highest levels of technological maturity.

The integrating sector is composed of three types of players. First, a few large integrators that compete with the external solutions adopted by the subsidiaries of multinationals. Second, some of the companies that also develop enabling technologies in Industry 4.0, thus making their business model profitable (the specialization strategy in technology development is limited because of the small size of the domestic market). And finally, by a limited network of national companies of smaller size, scope, and capability level (CNI, 2017).

The strategic nature of these companies and its relevance for the technology diffusion process are the basis for the Innovacred 4.0 program, launched in 2020 by the FINEP (Financiadora de Estudos e Projetos), of Brazil's Ministry of Science, Technology, Innovation and Communications. The program aims to support the development and implementation of actions towards the use of services for the adoption of enabling technologies 4.0 in production lines of agricultural and manufacturing companies with a turnover up to approximately USD 58 million.

Innovacred's operating regulations define the following roles for integrators: providing adaptation services, customizing and developing software, automating production processes, and managing industrial activities and the implementation of equipment such as sensors and others in order to integrate production processes. In terms of training, the program specifies the necessary equipment, the auxiliary units, the commands, and the sensors and software to be used".

In order to access financial resources (either for the purchase of equipment, software or the payment of the services provided by the integrating company), the beneficiary must present a digital solution that has been designed by an integrator accredited by FINEP itself. In this way, integrators are induced to become promoters of the program, while facilitating their involvement with smaller companies. To achieve this certification, the integrator must show proof of execution of at least 3 projects related to the implementation of digital solutions and validation of its technical capacity by the respective clients or industrial automation equipment suppliers. The integrator must also request individualized certification of the services that will potentially be financed, all of which are evaluated by a certification committee.

In 2019 the first 7 integrators were certified and, as of November 2020, another 14 joined the list, with another 20 integrators in the pipeline. Despite the first call for projects being launched the days prior to the spread of the COVID-19 pandemic, the program was able to finance 18 implementation projects up to date. 60% of projects corresponded to micro and small companies. Total financing represented more than 12 million reais, with an average ticket of 700,000 reais (approximately 140,000 USD) per adopting company. Banco Nacional do Desenvolvimento (BNDES) launched a financing tool with a very similar design (Crédito e Serviços 4.0.) on September 2020.

F. SENAI 4.0 (Brazil)

Outreach: National.

Type of initiative: Private – public.

Organization: National Industrial Learning Service.

Description: Technical assistance for the adoption of smart technologies.

Key dimension/s: Adoption – Awareness.

Brazil follows a more consolidated mode towards facilitating adoption, which builds on the successful experience of the "Brasil Mais Produtivo" (CEPAL/Ipea, 2018) program launched in 2016. For this purpose, Brazil's national industrial learning service, Serviço Nacional de Aprendizagem Industrial (SENAI), structured the SENAI 4.0 program. The initiative is inspired by the premise that insertion in Industry 4.0 should start from a strategy based on short term leapfrogging through the incorporation of low-cost technologies already available in the market that can deliver quick productivity gains.

The program is organized across three stages. The first consists of holding face-to-face meetings and free courses focused on raising awareness regarding opportunities for improvement. Then, combining a digital self-diagnosis of technological maturity with face-to-face interviews conducted by SENAI consultants, helps develop an exhaustive diagnostic and create an action plan for the transformation journey. Finally, the capability-building and monitoring & evaluation phase is triggered. This stage is linked to the "Brasil Mais Produtivo"'s Digital Mentoring program and involves a combination of professional training and remote learning, on top of the deployment of sensors and software to collect and visualize data.

The program defines a series of segments for technical assistance based on the maturity trajectory and the specific activity, inspired by the ACATECH model.[10] The different segments entail:

- Optimization: needs related to process improvement, mostly aimed at reducing waste and training in 4.0 topics

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[10] Acatech Industrie 4.0 Maturity Index is a six-stage maturity model that analyses the capabilities in the areas of resources, information systems, culture and organisational structure that are required by companies operating in a digitalised industrial environment.

- Sensorization and connectivity: opportunities linked to the ability to monitor production lines, aimed mostly at implementing real-time analyses and decision making
- Visibility and transparency: improvements related to the possibility of integrating data emerging from the sensorization process to the rest of the company's operations and making them available in the cloud
- Predictive capacity: opportunities related to the incorporation of predictive analysis solutions (such as big data and AI), aiming mostly at scenario building and testing
- Flexibility and adaptability: systems implemented to identify problems and generate flexible responses to customer demands for new products and services

The first three segments are those that correspond to the approach of the Brasil Mais Produtivo program and represent nearly 80% of the manufacturing companies in the country (CEPAL/Ipea, 2018). SENAI's Institutes of Technology and Innovation acquire greater relevance for segments 4 and 5, particularly around facilitating the performance of tests and contributing to the development of specific projects for the provision of customized solutions.

Consultants are a key element of the program, acting as industrial extension agents that ensure an adequate linkage with the companies. SENAI consultants intervene in i) the digital maturity assessment, ii) the preparation, in conjunction with the beneficiary company, of the action plan, and, iii) the measurement of results.

In this sense, the program first required the development of a specific methodology to "standardize" this link. Such effort entailed, for instance: designing questionnaires, evaluation matrices and intervention strategies, training SENAI managers, and defining lists of required skills and competencies to design targeted training programs (e.g., around how to conduct interviews or create a work plan). Finally, the project required the implementation of a pilot across 5 regional departments. The structuring of the pilot program was designed to simultaneously serve as validation and improvement of the methodology and as the first instance of the training program with SENAI consultants.

G. CAIME (Uruguay)

Outreach: National.

Type of initiative: Public.

Leading organization: Ministry of Industry, Energy and Mining - Council of Professional Technical Education - Technological Laboratory of Uruguay.

Description: Training center.

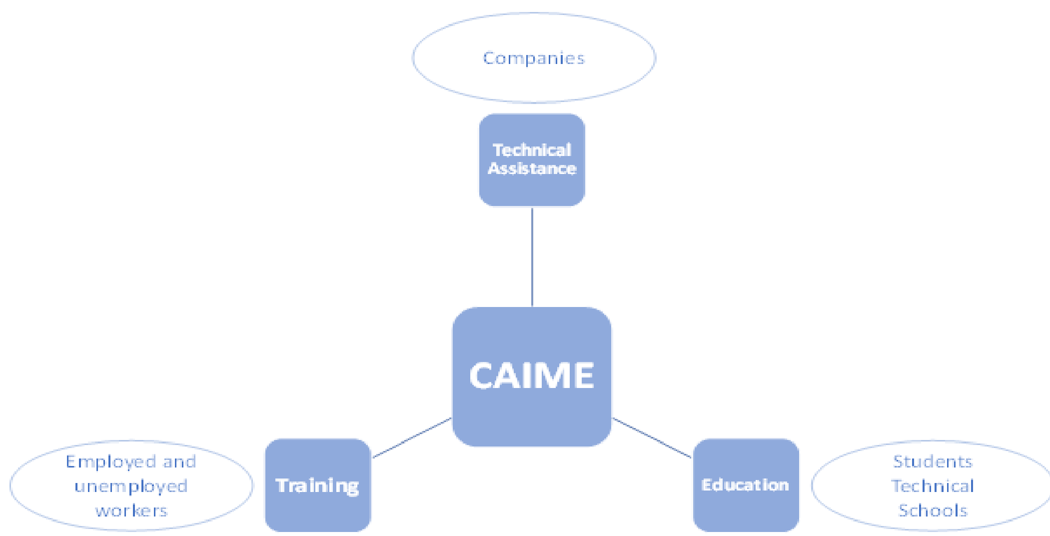
Key dimension/s: Adoption.

Uruguay's center for industrial automation and mechatronics, CAIME (Centro de Automatización Industrial y Mecatrónica) was inaugurated in February 2015. CAIME was an initiative jointly promoted by the Ministry of Industry, Energy and Mining, the professional education council UTU (Universidad del Trabajo del Uruguay) and the technology lab LATU (Laboratorio de Tecnología del Uruguay), with technical assistance from the UN's Industrial Development Organization (UNIDO). The Ministry contributed USD 1.8 million to fund the Laboratory equipment, which was acquired from the German company FESTO. In turn, FESTO, a world leader in automation that has a network of authorized and certified training centers in Mexico, Chile, El Salvador and, above all, Colombia, trained a professor sent by UTU to its headquarters and provided personnel to assist in the installation and set-up of the Laboratory. LATU, for its part, invested USD 500,000 on the design and construction of the building that houses the center.

The center has laboratories for industrial automation, electrical and electronic motors, pneumatics & hydraulics, virtual mechatronics, and a mobile lab. Equipment encompasses multiple technologies, such as Programmable Logic Controller (PLC), SCADA panels, open / closed control loops, AS-I, Ethernet and Vision systems. The mobile lab has Ciros Education simulation systems, which enables training through virtual versions of all the stations present in the industrial automation laboratory and others, such as industrial robots and PLC systems.

The center's "business model" involved mixed financing, resulting from the provision of services to multiple actors. UTU, the institution responsible for public technical education, both at secondary and non-university tertiary levels, finances the teachers (most of them engineers), who allocate a significant part of their time to the training of students from UTU´s educational centers, as well as from other technical education institutions. The center also provides technical assistance to companies and uses the facilities to train workers. CAIME has an agreement signed with the national institute for employment and professional training which subsidizes courses both to active workers and unemployed through a fund for "labor reconversion". The center has been able to consolidate its role with the educational system and to capture some demand for training from private sector workers and companies, but coordination with the consulting and technical assistance activities has remained limited so far.

Diagram 3
Center for industrial automation and mechatronics



Source: own elaboration based on interviews.

The capabilities of the center place it as a nodal asset to navigate the industry 4.0 journey, particularly given the modular nature of courses. Because of that nodal role, the Uruguayan chamber of industries CIU (Cámara Industrial del Uruguay) signed an agreement with the center to finance the training of two of its professionals in Chile. Upon their return, these professionals helped shape transformation plans for some associated companies, who would use CAIME's facilities to train their staff in their implementation process. In order to reinforce this goal, the center faces an increasing demand to strengthen its technological capabilities, particularly around sensors and controllers for the optimization of energy consumption and preventive maintenance.

H. Mind 4.0 (Mexico) and Digital Innovation Lab (Costa Rica)

Outreach: Regional / National.

Type of initiative: Public-private / Public.

Leading organization: Secretary of Economy and Labor & Nuevo León 4.0 Council / Ministry of Science, Technology and Communications.

Description: Open innovation initiative to bring innovative solutions for companies that become an industrial platform to accelerate start-ups.

Key dimension/s: Access - Smart Production.

In early 2019, the Nuevo León 4.0 Council launched the first call for the MIND 4.0 program. Adapted from the model developed in the Basque country (BIND 4.0), MIND 4.0 follows an open innovation strategy to bring innovative solutions to companies and accelerate start-ups operating in the smart manufacturing ecosystem.

The initiative begins with a call aimed exclusively at large industrial companies that act as anchor players[11] in their sectors within the region. The participating companies, among which are firms such as Frisa, Cemex or John Deere, must propose at least one challenge to be solved with 4.0 technologies and commit to contribute up to 50,000 USD for the development of the agreed proposal, sometimes fulfilling the role of first consumer.

Diagram 4
MIND 4.0: Partners and challenge

Partners	Challenge
Frisa-Posi	High temperature traceability tool
Metalsa-MANUFAI	Weld optimization through artificial intelligence
Questum-NubaHub	Monitoring system for the detection of faults in the induction furnace coils
Ternium-Prysmex	Industrial Critical Variables GPS / 3D Monitor
Sigma-Gesta Labs	Remote Support via IoT

Source: own elaboration based on interviews.

Once the challenges have been selected, the initiative triggers a call across start-ups from around the world to present solutions to that challenge leveraging 4.0 technologies. To be admissible, the solution must have already completed its stage of technological development, and the start-up should be looking for opportunities to scale. The *scale-ups* pitch their solutions and those that are selected advance to a negotiation process with the companies to refine the proposal. Finally, the parties sign a contract and implement the solution within 6 months. Throughout this process, the parties are accompanied by entrepreneurship nodes, formed by the groups of experts from local Universities. The first call attracted 21 large companies and 64 start-ups, while the second involved 25 large companies and 108 start-ups, from countries such as Spain, Canada or South Korea.

11 Either national or international.

Costa Rica's Ministry of science, technology and telecommunications MICITT (Ministerio de Ciencia, Tecnología y Telecomunicaciones) is designing a similar program based on an open innovation strategy: the Digital Innovation Laboratory. The approach consists of extending the experience of the first agriculture FabLab (specialized in technological management) to the manufacturing field. This FabLab was launched in mid-2019 in conjunction with the Inter-American Institute for Cooperation on Agriculture (IICA) and the national telecommunications fund FONATEL from the telecommunications superintendency (Superintendencia de Telecomunicaciones, SUTEL).

The Digital Innovation Laboratory expects to identify challenges from companies and partner with the ICT Chamber CAMTIC (Cámara de Tecnologías de Información y Comunicación) to attract members and entrepreneurs to propose solutions. The pilot ongoing pilot design would target a small group of diverse companies, including a multinational firm, a cooperative and a national medium-sized company. Technological managers would act as intermediaries between adopters and solution providers. The program contemplates the delivery of vouchers leveraging resources from the development bank system "Banca para el desrrollo" in order to finance the development of prototypes, thus engaging in a more embryonic stage than what the original MIND 4.0 program does.

III. An agenda for smart manufacturing in Latin America

The last section explored how the region began to follow the path that developed countries started some time ago in terms of promoting smart manufacturing policies. Moreover, the region's approach has been strongly influenced by the institutional experience of these countries, particularly Germany and the Basque Country of Spain.

Strategies towards ADP technologies applied to manufacturing take diverse forms around the world: industrial policies or science, technology and innovation plans, digitalization strategies or national digital agendas, etc.. Among developing country strategies, China´s "Made in China 2025" constitutes a particularly ambitious and relevant case. Made in China 2025 was adopted in 2015 as a comprehensive initiative to upgrade China's manufacturing industry from a manufacturing giant into a world manufacturing power. The strategy seeks to close the gaps with developed countries in innovation, efficiency in resource use, industrial structure, digitalization, and product quality.

In Thailand, for instance, the basic elements of the national strategy, Thailand 4.0, are embedded in the 20-Year National Strategy 2017–2036 and the 12th National Economic and Social Development Plan 2017–2021. Malaysia's National Policy on Industry 4.0 (Industry4wrd) seeks to boost the country's industrial performance and endorses efforts to achieve the SDGs. India launched the "Make in India" initiative, seeking to combine industry and Internet of Things (IoT) technologies. The initiative is complemented by the Digital India program, which intends to promote manufacturing and the use of ICT infrastructure (UNIDO, 2019).

Smart manufacturing strategies are also adopting diverse forms across the region. Colombia, for example, included Industry 4.0 in preparing the National Development Plan, as part of a national pact for a digital society and the 4IR (DNP, 2018). Brazil adopted the Science, Technology, and Innovation Plan for Advanced Manufacturing (MCTIC, 2017). Chile, despite being a latecomer to ADP technologies, is one of the first to adopt a strategy for it. The Strategic Program for Smart Industries (PEII) 2015–2025, announced in 2016, introduces a vertical approach looking into problems, needs and possible solutions for individual industrial sectors (CORFO, 2017). In Argentina, the Ministry of Industrial Development has recently announced the 4.0 Industrial Development Plan.

Despite the progress observed so far in the region, it's hard to develop yet an exhaustive assessment of the impact of the smart manufacturing agenda in the region. First of all, most of the initiatives implemented up to date are relatively young -ranging mostly from 2 to 3 years old- and therefore it is too early to consider the results achieved. Besides, its planning and execution has been heavily affected by the COVID-19 pandemic. While the pandemic has generated further momentum for accelerating the technological transformation, it created a strong need for adapting the dynamics of government operation while putting significant pressure on financial resources.

However, certain insights arise on the prevalent critical points affecting the region after a thorough inspection around the nature and scope of the interventions and their linkage with the main challenges faced by the manufacturing sector (explored in the second section of this article). The range of interventions and its scale vary significantly across countries, depending on the industrial structure and previous institutional development, among others. Precisely because of that heterogeneity (and the heterogeneity around the starting point of the manufacturing sector in each geography), there are certain nuances around the intensity of the pain points currently identified.

Besides the observed variability, we identified a set of common challenges inhibiting smart manufacturing across most countries in the region. Combining those common challenges with lessons from international experience, we came up with a set of recommendations for pushing the smart manufacturing agenda in Latin America.

A. Strengthen awareness among latecomers and laggards

Awareness about the potential and applications of advanced technologies in manufacturing is a precondition for the digital transformation. Yet evidence shows many manufacturing firms are unable to recognize the value and the specific solutions that may benefit them.

Awareness-raising actions in the region have tended to rely heavily on dissemination of successful cases, seminars and congresses on new trends and self-diagnoses. However, there are still few areas in the region that companies can take advantage to experience the impact of new technologies. Such initiatives can be fertile ground for public-private linkages and can also be used for training purposes.

Building awareness requires a strong understanding of the local context and how manufacturing firms think and operate to provide meaningful "demonstration effects". In India, policymakers intend public research infrastructure to showcase practical applications of ADP technologies, to raise awareness and demystify the concept through capacity building tailored to the needs of firms. Centers are located to match local manufacturing specialization and the competences of firms. For instance, the C4i4 Lab in Pune received a public grant of USD 2 million and raised an additional USD 700,000 in private funding to support local SMEs. The program starts with diagnostic studies to determine SMEs main challenges around smart manufacturing. The lab supports workshops and demonstrations of smart manufacturing applications—and pilots for adopting SME tailored solutions. According to the director of C4i4 Lab, drivers of success include nurturing close relationships with the industry associations, fostering interaction with higher education institutions both for training and skill development and involving college graduates in diverse activities (UNIDO, 2019).

Developing strong local networks through deep grassroot efforts is also key for success. In April 2017, the local government of the Zhejiang province in China launched "Enterprises Deploying the Cloud" to raise the awareness of manufacturing companies about cloud technology and its applications. The initial target was to assist 100,000 firms to adopt cloud technology over 2018–2020. Local governments organized more than 1,100 seminars for cloud training, covering more than 90,000 firms and 100,000 participants. Each industrial firm, regardless of size or type, was able to attend seminars intended to enhance its willingness and practical ability to use cloud technologies. As a result, more than 218,000 firms in Zhejiang deployed the cloud, bringing the total number of adopters in the province to around 268,000 in about a year of operation (UNIDO, 2019).

Another reference is the Mittelstand 4.0 Competence Centers in Germany. These Centers offer workshops, demonstration plants and networks with representatives of the complete value chain. SMEs are free to go and receive consultations and advice for free. The Mittelstand 4.0 Competence Centers are founded by separate consortiums consisting for instance of universities, Fraunhofer institutions and other external partners like chambers of commerce. Within these consortiums, each partner takes over a specific role due to their specific competence (e.g. 3D printing, flexible manufacturing, new business models, etc.). Currently, there are 23 Mittelstand 4.0 Competence Centers in total. 17 Mittelstand 4.0 Competence Centers focus on supporting SMEs with general issues and questions around digitalization. Additionally, six Mittelstand 4.0 Competence Centers focus on specific verticals and applications, such as IT, textile, e-Standards or usability, crafts, and smart building (UNIDO, 2019).

B. Expand last-mile connectivity for manufacturing firms

In terms of infrastructure, the region faces the double challenge of promoting investments in the new platform that will significantly accelerate the transformation process (5G) and incorporating a "firm centric" perspective to develop "last mile" connectivity, often ignored in the region's agenda. This is particularly relevant for SMEs. Smart industry entails network economies that derive from the fact that its maximum potential is reached when the transformation process goes beyond the factory, reaching suppliers and customers. In this sense, the benefits that large national companies and the subsidiaries of multinational firms can get out of the transformation process may be limited by the lack of connectivity and technological progress of SMEs within their value chains. This pain point can eventually lead to the reconfiguration of the supply chain and the displacement of local providers, creating further harm for the region.

The connectivity agenda should be complemented with adequate regulation to enable effective access and development of smart manufacturing solutions. In this sense, the homologation of protocols and the definition of rights and obligations regarding the use and protection of data are key drivers of investment in emerging technologies. Harmonization plays a key role too, particularly in terms of regional and global trade.

While the region has seen significant dynamism in terms of overall connectivity, little progress has been seen around the "last-mile", even more so from the perspective of manufacturing firms. Even though connectivity may be perceived as a non-issue for large firms in highly urbanized areas, the situation may significantly differ for smaller firms and firms operating in less populated areas.

Expanding connectivity for manufacturing firms requires going beyond updating regulations, opening the ICT sector to investment, and fostering broadband infrastructure. Ensuring adequate and affordable access to high-speed internet requires an extra effort, particularly in excluded geographies and for SMEs. Governments may turn to educational institutions and local and community centers to provide free or subsidized access to the internet. Ecosystem enablers such as technological and innovation hubs or industrial parks may play an important role too. And taxes and incentives should help in bridging geographical digital divides and increase access to adequate infrastructure.

Mobile technologies can play a significant role, particularly in geographies with low access to fixed broadband. In this sense, the deployment of 5G appears as a key priority in the agenda. Some of the most remarkable aspects of 5G involve: its ability to offer high availability and low latency connections, its energy efficiency, and the possibility of connecting thousands of devices to each antenna. This opens up a new range of applications and gives new impetus to IoT solutions.

5G primarily delivers value by enhancing three applications: enhanced mobile broadband, ultra-reliable low latency communication, and massive machine-type communication. The growth of 5G will benefit many firms among both users and suppliers. Within advanced electronics, three groups are particularly well positioned to realize gains: component and module suppliers, machinery and industrial automation players, and manufacturing players (Burkacky et. al, 2020).

Despite the momentum, much needs to be done in order to translate the potential into actual value. GSMA estimates 65 million of 5G connections in LAC by 2025, 10% of total projected connections for the region (GSMA, 2020).

C. Develop a culture of cyber-resilience

Threats to cybersecurity represent one of the largest risks for the global economy and poses significant challenges in terms of data privacy. In 2018, cyber-attacks were estimated to cause around 600 billion USD in damages, equivalent to 0.8% of global GDP (Lewis, 2018). Moreover, evidence in the region suggests attacks are shifting from random attacks to individuals to targeted attacks to companies (Kaspersky, 2020). Firms are particularly vulnerable to email attacks and offline contamination, such as USB devices.

Addressing this risk requires thinking beyond the technical solutions and shifting from a paradigm of cybersecurity towards a paradigm of cyber-resilience. Cyber-resilience involves not only adopting the adequate tools and methodologies to prevent attacks, but also developing the adequate skills and the organizational culture needed to mitigate the threat.

A study (ESI Thought Lab, 2020) found that 87% of executives believe untrained employees represent the biggest threat to cybersecurity. In this sense, final users may be the weakest link for achieving cyber-resilience. Users not only sometimes have attitudes of overconfidence, but there are also oversights regarding the update of software in their devices, the renewal of passwords, the detailed reading of the terms and conditions when they access certain information or applications, and even cases when accessing applications or content of dubious origin that easily arouse curiosity.

Beyond increasing investment in cybersecurity, some of the key recommendations involve for strengthening cyber-resilience involve: making cybersecurity hygiene a top priority, keeping management teams focused and aligned, relying heavily on advanced analytics and specialized teams, extracting greater value from cybersecurity tools (including for instance cloud workload security or endpoint detection), making more use of cybersecurity insurance, and enabling and empowering teams to work through secure, cloud-based platforms.

Other organizations such as WEF have taken this vision even one step further and suggested such threats should be addressed at the ecosystem level. In this view, different organizations should work together through cyber information sharing as a platform for developing collective resilience. For instance, MM-ISAC is an industry owned non-profit open to all companies in the mining and metals industry focused on sharing critical cybersecurity information through secure channels.

D. Improve affordability for SMEs

Making access to 4.0 solutions affordable is key in general and even more so in a region characterized by low economic growth and low access to financial resources.

Demand-driven interventions can provide meaningful support, particularly for small firms. For instance, the Zhejiang government has introduced diverse financial support methods to facilitate adoption of new technologies or foster innovation, particularly among SMEs. Voucher schemes lower the cost of cloud technology, and firms can redeem those vouchers with cloud platform service providers. Based on technical evaluation, the government selects certain firms to benefit from subsidies for significant pilot or demonstration projects (UNIDO, 2019).

The big challenge in this dimension is around creating enough scale and making impact sustainable, particularly given subsidy-based interventions´ strong dependence on the availability of financial resources. In this sense, creating a significant and long-lasting impact in this dimension may require going beyond traditional levers for improving affordability (i.e. subsidized credit and demand-driven subsidies) and exploring more innovative approaches. For instance, consolidating elements of traditional offerings (e.g., cloud space, software architecture, additive manufacturing molds) to operate as shared solutions can significantly alleviate the cost for SMEs.

E. Create opportunities for startups and accelerate solution development

Beyond strengthening access and the adoption of advanced digital technologies, governments and private sector leaders should work together on expanding the solution development ecosystem. Promoting the solution development is not only good for facilitating the creation and adoption of adequate solutions by manufacturing firms. It also stimulates growth, job creation, and the diffusion of technologies and capabilities.

Startups are seeing momentum and benefiting from initiatives that help them access to capital and accelerate growth. The BIND 4.0 program, introduced in 2016 in the Basque Country, was the first international public–private initiative to function as start-up accelerator specialized in Industry 4.0 solutions to support start-up development and growth (UNIDO, 2019). It mobilizes local Basque Country firms—in healthcare, energy, agrifood and manufacturing —to function as catalysts by establishing contact with innovative entrepreneurs, either domestic or foreign. BIND 4.0 was a source of inspiration for similar efforts across the globe, including the MIND program in Nuevo Leon.

Korea launched a network of 19 Smart Manufacturing Innovation Centers across the country to support SMEs and startups with an aspiration of supplying 30,000 smart factories by 2025 (KOSMO, 2021). For instance, the Pohang Techno Park focuses on supporting steel-based industries by promoting technological innovation and the foundation of companies with excellent technology through incubation, joint research, education and training, and dissemination activities. Its core activities involve a) fostering technological startups to create an entrepreneurial ecosystem by expanding their financial support and investing in and supporting funds for local startups, b) discovering leading technological companies and fostering companies powered by innovative growth by making improvements to lease conditions for companies through expansion of support infrastructure, and c) intensively fostering future strategy industries in Pohang and give support to them (Pohang Technopark, 2019).

As part of the "Enterprises Deploying the Cloud" in Zheijang, the city government established a cloud service platform to coordinate cloud service providers, cloud technology design developers, software and hardware developers, system integrators and industry associations to assess an enterprise's application and formulate plans for detailed cloud transformation projects. To meet firms' needs, the province incubated 12 industrial cloud application platforms in textiles, commerce, finance and intelligent customer service.

Creative spaces can advance and democratize manufacturing development, particularly in excluded geographies. Various forms of creative spaces since the early 2000s, generically referred to as modern "do it yourself" (DIY) movements—such as fab labs, hackerspaces, makerspaces, tech/innovation hubs and creative spaces—are innovative attempts at bridging gaps left by markets and states in providing education, building capacity and furnishing smart manufacturing infrastructure.

Although different, DIY movements generally offer access to digital technologies that facilitate sharing knowledge and diffusing creative ideas among communities. They offer common spaces—physical or cyber —where individuals can collectively create or tinker with existing products to suit their needs with digital equipment and hard tools. The movements often offer possibilities for networking with possible investors, lenders, customers, and business partners.

DIY movements usually search for solutions to development challenges at the individual or community level. But they could offer new avenues for public engagement in manufacturing, opening spaces for inclusive and sustainable patterns of manufacturing development (UNIDO, 2019).

F. Invest in developing capabilities and skills

It takes commitment and substantial resources to develop the capabilities required to take up new technologies and assimilate any associated productive transformations. The immense effort is required to upskill and reskill the current workforce and the development talent as one of the greatest challenges in the region and across the globe. The lack of large centers for the development of new technologies (usually found in developed nations and technology frontrunners) and the relative weakness that the vocational training systems present in many of the countries of the region accentuate the lack of qualified personnel for this task.

That lack of talent extends to technical assistance services. As SENAI's experience shows, the first challenge that programs of these nature face to reach enough scale is the development of a strong network of experts in new technologies, particularly in geographical areas with less industrial density. Here the region, with the exception perhaps of Brazil, has an additional difficulty because of the weakness of its electronics industry and the lack of articulation between its software sector and its manufacturing industry.

Lack of capable integrators appears as a critical challenge for the sector. Integrators with a software background usually lack the experience and know-how, while those coming from the automation ecosystem lack the IT capabilities. In many countries this becomes even more challenging as the domestic talent market related to services for manufacturing firms is limited by its low purchasing power capacity when competing with global talent attraction opportunities. Besides, the small size of domestic markets discourages the establishment of capabilities that go beyond distribution by global companies. This means that (as also happens with robots), many countries in the region lack an adequate network of maintenance services, significantly raising its cost and reducing the degree of adoption, and consequently affecting long-term competitiveness.

This phenomenon reinforces the importance of generating a network of local companies with the capabilities to develop or adapt solutions. Addressing this challenge seems more feasible on the software segment than on the hardware segment, both because of the accumulated capabilities and the different weight of the economies of scale. In any case, with few exceptions, most countries in the region lack the facilities that serve as testbeds for the deployment of these solutions. Moreover, this is accentuated by the lack of development of the scientific-technological ecosystem, which is relatively stronger in basic research than around technological development.

The Basque Country is experimenting with new approaches to training, upskilling and career reorientation according to emerging requirements of firms. Cluster organizations lead in implementing human resource development strategies, building on existing training models with upgraded teaching facilities and learning environments and testing new delivery methods. For instance, the Association of

Electronic and Information Technologies (GAIA) runs pilot programs, some in collaboration with the Department of Employment, Social Inclusion and Equality of the Provincial Council of Bizkaia, to undertake professional retraining in ICT fields with high demand for employment, targeting youth (GAIA, 2019).

DIY movements can also play an important role here. While they are commonly included among innovation policy tools to strengthen digital ecosystems around start-ups in advanced economies, the movements' core functions involve education, learning, problem solving and peer-to-peer learning. They can also foster university involvement, because many DIY facilities in developing countries are located within higher education organizations, which, in turn, provide equipment and trainers. The facilities train people in using digital equipment and tools to make prototypes as part of projects. Students gain experience with advanced digital equipment to increase their employability but also to venture into the market as entrepreneurs.

G. Strengthen integration and collaboration across key stakeholders

A first aspect has to do with the need to develop and articulate a cohesive and coherent strategy that articulates the different stakeholders. This implies establishing a clear orientation on the priorities, determining a budget allocation consistent with it, and creating institutional spaces that not only serve to exchange views and information, but also include effective mechanisms to coordinate the actions of different ministries and the private sector. Except for some successful experiences such as Nuevo Leon in Mexico, there is not much track record in the region.

Multistakeholder and participatory approaches are key across different layers of decision making. Through multi stakeholder, participatory processes policymakers can foster shared visions of strategic goals, identify tested policy tools for scaling up, inform the design of policy incentives or uncover gaps between different types of firms. Emphasis should be put on articulation with the scientific and technological community.

In Turkey, for instance, under the overall leadership of the Higher Council of Science and Technology (BTYK), the Scientific and Technological Research Council (TÜBİTAK) coordinated the Smart Manufacturing Systems Technology Roadmap, which builds on digitalization and interaction within the scope of ADP technologies and factories of the future (TÜBİTAK, 2019). Through a comprehensive participatory process, including firm-based surveys, it was possible to define three technology groups —digitalization, connectivity and future factories— with 10 technology-based strategic targets and 29 critical products, research and development (R&D) projects and priority sectoral applications. Similar consultative processes to inform the development of national strategies can be identified in countries like Argentina or Brazil.

Participatory approaches can help detect emerging changes even at an early stage. When combined with policy tools such as strategic foresight and market intelligence services, participatory processes can help policymakers anticipate opportunities, threats, or vulnerabilities early on. Given the rapid pace of ADP technologies, collaborative multi stakeholder approaches can identify where supporting capacity development is needed and help domestic firms identify or anticipate changes in demand and in the structure and dynamics of value chains.

Collective thinking underpinning the elaboration of roadmaps or national strategies often informs proposals for additional diagnostic studies targeting strategic sectors or individual technologies, while governments aim to leverage ongoing initiatives and pilot projects.

International and regional collaboration and policy coordination can play a key role too, particularly in developing countries. Several developing countries still lack a formal strategy and are engaged in consultations and other participatory policy-making processes with a view to developing roadmaps or national strategies through the work of special task forces or working or consultative groups.

Kazakhstan's new digitalization strategy, Digital Kazakhstan, benefited from the collaboration of Germany's Fraunhofer Institute with the Kazakhstan Ministry of Industry and Infrastructure Development (MIID, 2018). Activities included a diagnostic study on the readiness of about 600 domestic companies to adopt smart manufacturing. Enterprises in textiles, food and other sectors are piloting model digital factories and, based on results, plan to popularize digital technologies, demonstrate the effects of digitalization, identify barriers to digitalization and develop advanced support tools. A technological audit, using the Fraunhofer Institute's methodology, plans for local companies to digitize production processes, business models, equipment maintenance, supply chains, customer interactions, training, and other relevant areas.

Spaces for regional collaboration can play a key role. In 2015, China and Germany agreed to jointly promote the readiness of their respective economies for smart manufacturing by linking Made in China 2025 and Industrie 4.0 through a memorandum of understanding signed by the China Ministry of Industry and Information Technology (MIIT) and the German Ministry of Economy and Energy. Collaboration is already bearing fruit through a jointly established Sino-German Industrial Park as a platform to connect Chinese enterprises and German technology. In 2016, MIIT selected pilot demonstration projects in accord with the Sino-German smart manufacturing cooperation arrangement, with Chinese firms applying according to their own development strategy. Sino-German experts evaluated projects and confirmed the first batch of 14 pilot demonstration projects, for example, the Industry 4.0 exploration for the iron and steel industry between China Baowu Steel Group Corporation and Siemens (UNIDO, 2019).

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Innovation, automatization, and digitalization of production processes entail many positive externalities for companies. These include higher levels of competitiveness and productivity brought about by improving operational processes, facilitating access to new markets, easing product differentiation and optimizing the entire value chain. Smart manufacturing trends capture these changes, highlighting opportunities and challenges for companies. Various factors condition the adoption of new technologies in companies in Latin America and the Caribbean, thus hampering innovation and technological change, but these can be overcome with adequate strategies to provide the necessary environment and incentives to promote innovation. This document provides an analytical framework for the design of such strategies, based on the study of a set of initiatives, both public and private, aimed at promoting smart manufacturing. It is intended to serve as a guide and inspiration to continue fostering technological change and industrialization policies in the region.

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