BUILDING THE FUTURE OF BRAZILIAN INDUSTRY VOLUME 1 DISTRUPTIVE TECHNOLOGIES AND INDUSTRY: CURRENT SITUATION AND PROSPECTIVE EVALUATION VOLUME 2 DISRUPTIVE TECHNOLOGIES AN....

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MOBILIZAÇÃO EMPRESARIAL
PELA INOVAÇÃO

Indústria
2027
mei MOBILIZAÇÃO EMPRESARIAL PELA INOVAÇÃO

FINAL REPORT

BUILDING THE FUTURE OF BRAZILIAN INDUSTRY

VOLUME 1
DISTRUPTIVE TECHNOLOGIES AND INDUSTRY: CURRENT SITUATION AND PROSPECTIVE EVALUATION

VOLUME 2
DISRUPTIVE TECHNOLOGIES AND INDUSTRY: CHALLENGES AND RECOMMENDATIONS

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INDUSTRY 2027
Risks and Opportunities for Brazil in the face of disruptive innovations

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Indústria 2027
mei MOBILIZAÇÃO EMPRESARIAL PELA INOVAÇÃO

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2018

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ABSTRACT

A changing world

The world is going through the first stages of deep **changes in production patterns, competition, business models, consumption and lifestyles**. The vectors of these changes can be found both on the demand side, stemming from population aging, from aspirations and frustrations of the middle classes, and from challenges associated with climate change; and on the supply side, stemming from faster **advancements in science and technology**, from the entry of **new players into international competition**, and from the **adoption of national proactive science, technology and innovation strategies** (ST&I).

International trade has grown and competition has increased significantly since the 1990s, when production in certain industrial sectors became increasingly fragmented geographically into what came to be known as global value chains. Companies in advanced industrial countries outsourced production and focused on the sophisticated links of value chains. New manufacturing companies, mainly in Asia, entered labor-intensive stages, exploiting cost advantages. However, over the subsequent decade Asian companies automated their processes intensively, accumulated economies of scale and promoted advancements in research and development (R&D) that enabled them to compete for global leadership in several segments, such as in the information and communication technology (ICT), Internet access devices, microelectronics and consumer durables segments.

These geoeconomic changes led to the emergence of **decentralized and sophisticated production structures**. Leading companies in the global value chain have engaged partners (domestic and international companies and research institutions) in **multi-partner, interdisciplinary and internationalized innovation ecosystems**. The ecosystems on the technological frontier are characterized by multiple and dense links of cooperation, interdisciplinarity and participation of international centers of excellence.

At the same time, **the pace of technical progress has gained speed**. Clusters of combined and synergistic innovations are emerging **with sufficient strength to produce disruptive effects** on business models, on the determinants of competitiveness and on market structures in all productive activities. **What are these innovations all about?** What are their constituent elements? How do their costs and markets evolve? What is the rate of their dissemination? Is this disruptive potential already being felt in all technologies and in all productive activities?

Have these **innovations** emerged as "natural" processes or **are they being built** through long and persistent interactive processes between the world of science and technology, the business world, and the world of public policy? To what extent do these processes **anticipate and respond to societal challenges** or to the demands of competition and markets? Is it possible to identify **new business models** adopted to take advantage of opportunities derived from these new technologies? What **key factors** will determine **competitive success**? What changes can be expected in market structures when these technologies become economically relevant? Are incumbent companies systematically seizing these new opportunities or are they being threatened by new entrants?

Answering such questions is an essential step in a project designed to build the future of Brazilian industry.

What are combined, synergistic and disruptive innovations?

Solutions combining and leveraging knowledge-intensive innovations are being introduced and disseminated to create new markets and new business models, leading to significant social and economic impacts. The ability to tackle technical challenges increases significantly when different scientific and technological bases are combined: for example, genomics with high performance computing for DNA sequencing; advanced microprocessors for image recognition with robotics for self-driven vehicles; or the Internet of Things (IoT) with artificial intelligence and advanced communication networks for smart grids and traffic control in urban centers.

Despite differences in their knowledge bases, all technological solutions with disruptive potential have two **elements in common: sharply falling costs and fast-growing markets**. For example, the cost of sequencing human genomes fell from US$95 million in September 2001 to US$1,000 in September 2017. The average cost of sensors for the IoT was US$1.30 in 2004 and it may drop to as low as US$0.38 in 2020. The cost in US$/KWh of lithium-ion batteries declined from US$1,000 in 2010 to US$209 in 2017. In 2017, sales of big data solutions were estimated at US$34 billion and they could triple in eight years. Expenditures with robotics are also likely to triple by 2025 to US$70 billion.

The prospective evaluation carried out under the Industry 2027 project suggests **that all productive systems will be coexisting with disruptive technologies in up to ten years. Although time is scarce, Brazilian industry can and should prepare for these approaching changes in technology.**

The **business models** of companies and their value chains are **evolving into integrated, connected, smart and "servitized" models**. They are integrated and connected because the different links of value chains and intra-company activities will become so close that their boundaries are tending to disappear. They are smart because economic and technical information will be captured and processed online, making it possible for decisions on actions and reactions to productive phenomena to be delegated to digital equipment and systems through artificial intelligence algorithms. Models of this nature make it possible for companies to provide intrinsically complementary goods and services or to offer goods to be used in the form of services instead of selling them.

Such models are paving the way for companies to support their strategies with **new competitive factors**: in processes and value chains, these new technologies make it possible to **optimize the management of the entire chain and enhance the accuracy of efficiency parameters**, combine **scale with differentiation and customization** and, in the limit, **customize products**. For example, precision agriculture and personalized medicine are concepts that have become operationally feasible based on clusters of combined and synergistic innovations.

Under increasing competitive pressure, companies need to transform themselves and adopt new business models. As a result, **market structures have become more vulnerable to the entry of new competitors into the market**, more flexible in the face of different business formats, and more permeable to leadership changes.

National strategies for building futures

Never before have so many countries prioritized science, technology, and innovation as today. The United States intends to maintain its leadership in the field of ST&I and regain manufacturing capacity. Public and private spending on research and development (R&D) in 2018 is estimated at US$533 billion (2.7% of GDP). In China, this spending is estimated at about US$279 billion (2.3% of GDP) and it tends to grow. The Made in China 2025 plan will not be over this year; it is the country's ambition to become a world superpower by 2049. Germany, which is known for its *Industrie 4.0* initiative, has plans to strengthen the hegemony of its mechanical and chemical industries, among others. German investment in R&D in 2017 was estimated at US$105 billion (2.8% of GDP).

Despite differences in legacies and ambitions, a comparison between countries with a strategy underway reveals common foci, namely: sustaining international competitiveness, developing innovation ecosystems, creating jobs and qualifying people, supporting smaller companies, paying attention to the quality of life, health and aging of the population and ensuring environmental sustainability. **These future-building strategies are linked by common national views, led by the highest executive authorities in each country, supported by public-private consultations, and rely on significant and predictable funds earmarked for them**.

The opportunity of Industry 2027

A changing world, more intense international competition based on innovation, technology clusters emerging with disruptive power, and countries implementing strategies to promote productive and innovative ecosystems have led the National Confederation of Industry (CNI), through the Euvaldo Lodi Institute (IEL), under the Entrepreneurial Mobilization for Innovation (MEI), to mobilize the Economics Institute of the Federal University of Rio de Janeiro and the Economics Institute of the State University of Campinas to carry out the **"Industry 2027: risks and opportunities for Brazil in the face of disruptive innovations" project**.

The Industry 2027 project identified trends and **impacts of disruptive technologies** on different production systems in a five- to ten-year horizon; assessed the capacity of companies to deflect risks and **seize opportunities**; and developed recommendations for the strategic planning of companies and inputs for public policy making.

The study was focused on technology clusters and production systems with sectoral foci. **The technologies that were studied were defined based on their potential disruptive impact** and organized into eight technology clusters based on the similarity of their technical bases. **Industry was stratified into ten production systems and 14 specific sectoral foci** selected according to the economic importance of the activities in question for the country's industrial matrix and to the potential impact of innovations on each of them.

These clusters are the following ones: Artificial Intelligence, Big Data, Cloud Computing; Internet of Things and its respective systems and equipment; Smart and Connected Production (advanced manufacturing); Communication Networks; Nanotechnologies; Advanced Bioprocessing and Biotechnologies; Advanced Materials and New Energy Storage Technologies. The production systems and sectoral foci are the following ones: Agroindustries and Processed Food Products; Basic Inputs and Steelmaking; Chemicals and Bioeconomics; Oil and Gas and Deepwater Exploration and Production; Agricultural Capital Goods and Machinery and Implements, Machine Tools, Electric Engines, Energy Generation, Transmission and Distribution Equipment; Automotive Complex and Light Vehicles; Information and Communication Technologies and Systems and Telecommunications Equipment, Microelectronics and Software; Pharmaceutical and Biopharmaceutical Products; Consumer Goods and Textiles and Wearing Apparel.

During **14 months**, since March 2017, a team of 75 experts of recognized competence in technologies, industrial sectors, and innovation policy was mobilized in Brazil and abroad to contribute to Industry 2027. A field survey was carried out with approximately 750 industrial companies in the second half of 2017. Well-informed representatives of these companies expressed their opinions on the current stage and prospects of digitization in their companies. **The development of the Industry 2027 project was monitored by MEI** at all meetings of leaders and MEI Dialogue sessions. A supervisory committee monitored its implementation and defined strategic guidelines; the reports were enriched by inputs from the technical teams of CNI, IEL and SENAI, and IEL ensured the project's timely implementation. **These are the main assets of the Industry 2027 project: the knowledge and competence of well-informed and specialized professionals**.

Two warnings should be made at this point. First, this project mainly considered technological solutions that could be commercially available by 2027. Solutions that may only become available after 2027 were not analyzed in depth. Second, changes that technical progress will bring about in other dimensions of economic and social life were not directly considered. Impacts on consumption patterns, on the labor market and occupations, and on the regional configuration of ecosystems, for example, were only considered when deemed relevant to the competitiveness of companies.

Challenges for Brazilian industry: chasing moving targets

Brazilian industry is characterized by a diversified and differentiated framework; its productive systems and even each economic activity are marked by the coexistence of companies with varying levels of capacity and competitive performance. Thus, it is not possible for it to use only the most advanced generation of digital manufacturing technologies as a benchmark, as Germany does.

The Industry 2027 project carried out a prospective analysis of the digitization stage of Brazilian industry, distinguishing between four generations of digitization (G1, G2, G3 and G4), ranging from that of isolated digitization (G1) to integrated, connected and smart companies (G4). Representatives from approximately 750 companies reported (i) the stage in which their companies were in 2017 and the stage in which they expected them to be by 2027; (ii) how their companies are preparing for the future; and (iii) what is, in their opinion, the likelihood of the most advanced generation becoming dominant in the sectors in which their companies operate. The most important results are the following ones:

- According to 65% of the companies' representatives, G4 will become dominant in sectors in which their companies operate by 2027. They suggested, therefore, that their companies will face competitors with integrated, connected, and smart business models.
- In 2017, approximately 75% of the companies are in the G1 and G2 stages; only 1.6% of the companies see themselves as operating in the G4 stage. The starting point is therefore challenging.
- In 2027, major advancements are expected: approximately 60% of the companies expect to be in the G3 or G4 stage in the future. Forced-march modernization is expected.
- Advanced companies (G3 and/or G4 in 2017 and by 2027) are 66% more likely to be larger, have high capacity, and have plans underway to implement systems of the expected generation; passive companies (G1 and/or G2 in 2017 and by 2027) are 75% likely to be small, have low capacity, and have no plan in place.

- Regardless of the structural or behavioral characteristics of the companies, investing in new technologies provides a positive return; these new technologies can be implemented gradually, according to the availability of funds and to the stage of development of the organizations, but such action should not be postponed.

The analysis of production systems of the Industry 2027 project was carried out in three consecutive steps: (i) identification of risks and opportunities for each of the ten productive systems (and their sectoral foci); (ii) comparative analysis of the systems, grouped into four groups of sectors selected according to the similarity of their function or to the nature of the activities they carry out in the economy, namely, innovation diffusion sectors, specialized and advanced knowledge activities, producers of intermediate inputs, and suppliers of consumer goods; (iii) location of groups of companies (and their structural characteristics in terms of production system and size) in three different stages of development, distinguishing between companies evolving on the technological frontier, companies capable of keeping up with the productivity frontier, and companies that need to get closer to the productive efficiency frontier. The distances from the technological and production frontiers were the anchors based on which recommendations were issued for business planning and public policies.

Assumptions for building the future

International experience shows that building robust national innovation strategies requires consensus on a common national vision. These strategies must be built on existing legacies, recognizing weaknesses and strengths; they must set ambitious goals and targets to take advantage of opportunities; and they must be realistic and pragmatic in the actions they contemplate.

For these strategies for new technologies to be actually implemented they require: (i) prioritization at the highest level of government and the existence of shared goals with private-sector counterparts; (ii) substantial investments in training human resources; (iii) enforcement of regulations and pro-innovation incentives; (iv) modernization and increased response capacity on the part of the State; and (v) implementation of actions through programs and instruments coordinated and aligned with the needs of companies and monitoring of their results.

Naturally, fundamental conditions to facilitate the implementation of these national strategies include resuming sustained economic growth with competitive interest and exchange rates; increasing investments in infrastructure and institutional reforms (tax, fiscal, financial reforms); ease of doing business and legal certainty. However, the country's administration should not condition the implementation of a national innovation strategy to the existence of these systemic conditions. The innovation strategy must be given high priority and involve persistence and a long-term vision, apart from being preserved even during unfavorable cyclical stages.

Moving targets: implications for companies and public policies

In addition to common directions, companies close to the technological frontier or to the productivity frontier and those that need to shorten distances from the production frontier face quite different competitive challenges. These groups of companies face distinct demand and competition pressures, have different skills, and operate in specific production and innovation ecosystems. Obviously, the implications for competitive strategies and public policies will also be specific for each group.

For **companies and ecosystems that can evolve on the technological frontier**, the recommended strategy is that of competing for differentiation, anticipating or creating markets, and remaining on the alert for opportunities for mergers and acquisitions with the aim of acquiring new competencies. Key competencies to be stressed here include those of generating, using, and disseminating advanced innovations and different knowledge bases through investments in R&D and by co-leading networks of production and innovation ecosystems, including day-to-day control and monitoring by the senior management of the organizations. These ecosystems should strive to strengthen the scientific and technological base of interdisciplinary networks (including international ones) with universities, research centers and suppliers; favor startups in hubs and business incubators; and identify challenges and propose solutions speedily. For this purpose, it is necessary to promote public-private concertation around programs and plans, which requires building consensus between public and private interests; implement actions through programs with specific foci and specified leaderships, in fine tuning with the private sector; carry out joint actions with development and regulatory agencies; and monitor and evaluate results on an ongoing basis. With respect to financing for disseminating technological solutions designed to promote productivity gains in the economy, securing public finance and private engagement is recommended using all the available instruments, such as subsidies, credit, and venture capital, to support the innovation cycle as a whole with co-participation of the private sector for the purpose of sharing risks. Large enterprises should also engage in corporate venturing with technology-based companies. Finally, regulations should be designed to foster innovations that exploit technological frontiers and public procurement should be guided by missions for priority programs associated with new technologies.

For **companies and ecosystems capable of keeping up with the productivity frontier**, the recommended strategy would be that of investing in integrated, connected, and smart business models covering the entire value chain to maximize productivity gains and sustain international competitiveness. Key competencies for these companies include engineering and R&D skills and market knowledge to seize product/service differentiation opportunities and use (or co-develop) new materials in advanced digital components and solutions and day-to-day control/monitoring by the senior management of the organizations. These ecosystems should give priority to engineering and R&D

and to identifying challenges and proposing solutions speedily; they should also favor startups in hubs and business incubators in the long-term and make efforts to evolve into interdisciplinary networks with research centers, suppliers and customers. With respect to financing, organizing public funding for risk-sharing programs with the private sector is recommended. Companies should also invest in launching and/or advancing in the use of digital technologies, complementing public funding, and they should strive to engage in corporate venturing with technology-based companies. Regulations should be designed to ensure precision, quality, safety (including data), and environmental sustainability.

For **companies and ecosystems that need to draw closer to the production frontier**, the recommended strategy involves investing in knowledge and implementation of digital solutions to gain productivity while strengthening business management and the ability to deliver quality and price efficiently. For these companies, the key competencies are the capability to manage their business, especially their production, and having the required knowledge to specify and implement more appropriate technological solutions for their business. For the advancement of ecosystems, it is recommended that public and private technological support institutions and the SENAI Institutes take on the role of leading networks and motivating companies, with specialized technical service centers playing the role of providing digital solutions to promote basic industrial technology and institutions that support business management, such as SEBRAE, fostering massive dissemination of new practices associated with digital technologies. It is imperative that participants in production chains (especially large upstream or downstream companies) take part in these ecosystems to qualify their suppliers or customers and that experiments to demonstrate digital solutions such as production lines and testbeds are promoted. With respect to financing, it is crucial to promote favorable credit conditions to finance the purchase of equipment, software, system integration services, and other appropriate digital services for companies and ecosystems. To foster the dissemination of new technologies, programs for the provision of specialized technical services should be oriented to tackling specific challenges associated with basic industrial technology, with expansion goals organized into networks (for example, SENAI networks), and programs in support of business management (such as the More Productive Brazil program) should be massively and significantly expanded with the aim of disseminating digital solutions appropriate to the profile of the companies with spatial, sectoral, or thematic foci and duly established goals and counterparts. With regard to regulations, they should be designed to induce the supply of externalities.

Building foundations for all

With regard to **human resources training**, it should be pointed out that the Brazilian public and private professional training system, especially SENAI, are strategic agents to improve the qualification profile of Brazilian workers. Steps must be taken toward

(i) evolving from “training centers” to “learning centers”; (ii) expanding and diversifying professional training programs to develop and renew skills throughout workers’ lives; (iii) anticipating an preventing needs in terms of skills and talents of workers and companies; (iv) including learning and use of digital technologies at all levels of education; and (v) promoting studies and debates on the impacts of technical progress on occupations, qualifications and labor, income and social benefits.

In order to **build capacity in small and medium-sized enterprises (SMEs)**, it is necessary to massively expand programs on entrepreneurial training, technical assistance, and technical/metrological services, such as the More Productive Brazil program. These programs should be designed to promote rules and standards designed to facilitate the dissemination of new technologies, ensure interoperability, and guide the operation of existing networks that provide assistance to SMEs. It is also necessary to disseminate integrative digital solutions and software, modular experimental platforms, including for lean manufacturing and energy efficiency, through the SENAI network of Technology Institutes and Innovation Institutes in partnership with SEBRAE, and to finance such solutions through public financial institutions. In order to build capacity in SMEs, it is necessary to mobilize credit, grant, and venture capital instruments with the aim of structuring permanent engineering and R&D activities in these companies. Finally, the need to strengthen incubator and accelerator networks and ensure favorable tax treatment to venture capital funds should be emphasized.

With regard to **regulatory aspects**, there is a need for contemporary and efficient regulation, which fundamentally requires updating legal frameworks for communications, ST&I, government procurement, biodiversity, network privacy and security, research and applications derived from advanced genomics techniques, and the “Civil Framework for the Internet of Things.” There is also an urgent need to speed up the process of building capacity in and digitizing regulatory agencies/public companies, particularly the National Institute for Industrial Property (INPI), the National Health Surveillance Agency (ANVISA), the National Telecommunications Agency (ANATEL), and the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA).

With regard to **sectoral agencies**, urgent steps must be taken to converge and standardize normative concepts related to innovation and R&D (including those adopted by the Brazilian Federal Internal Revenue Service), with a view to increasing efficiency and legal certainty. In addition, sectoral funds managed by sectoral agencies should be made available on a predictable basis and partnerships should be forged with funding agencies around challenge-driven technology development initiatives organized by programs, in line with the successful experiences of the Brazilian Company for Industrial Research and Innovation (EMBRAPII) and of the Inova Empresa program, with more non-reimbursable funds.

In order to **promote development with legal certainty**, it is necessary to decompress federal funds allocated to the ST&I system and define priority projects and programs at the highest levels of government, with goals shared with the private sector. It is recommended that the scale of support to innovation provided by federal financial institutions is increased through financing, including through non-reimbursable finance, and capitalization at appropriate costs and conditions (examples such as those of EMBRAPII should be strengthened and expanded), so as to ensure the availability of funds during all the different phases of priority projects, especially during the scaling up and manufacturability phases. For this purpose, provision should be made for allocating additional funds - on a predictable basis and without the possibility of the Federal Government using them to pay other bills or reduce spending - to building capacity in public and private science and technology institutions. It is also recommended that the Law of Good is improved by increasing its deductions, allowing for external R&D to be partially hired, including incentives for investing in startups, seed capital, angel investors, venture capital, etc. In addition, in order to ensure legal certainty and for companies to enjoy the incentives provided for in the law, it is important to ensure the convergence of legal concepts and rules to standardize enforcement criteria.

An integrated, connected and smart State - a digitized State - is required to promote efficiency gains, cost reduction, transparency, quality, and agile services (red tape reduction). This requires building capacity in public managers to prospect, plan, implement and evaluate programs to promote the generation, use and diffusion of new technologies. It also requires efforts to coordinate agencies and institutions and ensure consistency in the management of financial and non-financial instruments through integrated, smart, and transparent management systems.

International experience shows that **society should discuss new ethical and regulatory issues**. Because such new topics require attention, it is recommended that comprehensive and representative discussions and public consultations are held to validate proposals for: interoperability of standards and protocols, database ownership, personal privacy, communications and information security for companies, use and manipulation of human, animal and plant genomes, property and rights of protection of genomic data or of biodata of people or living organisms, recycling of inputs, parts and pieces and equipment related to bio- and nano-materials, and digital technologies.

Brazil can and should build the future of its industry

Countries intending to play a prominent role in a multipolar and competitive international scenario build their future proactively based on long-term, stable national innovation strategies legitimized by their respective societies and managed at the highest levels of government.

Brazil has no more time to lose: the powerful wave of ongoing technological innovations exposes risks of setbacks and opens up opportunities. If Brazilian industry doesn't keep pace with this wave, it runs a serious risk of losing substance, leading society to give up achieving more added value (wages, profits, taxes) and generating new services and jobs.

On the other hand, combined and synergistic innovations provide several windows of opportunity for Brazilian industry to develop new specializations and strengthen its competitive capacity on a sustainable basis. There are sectoral peculiarities and, after studying them, it was possible for the I2027 project to indicate how the response capacities of the private sector can be strengthened. Based on a broad mapping of international experience contemplating successful programs and initiatives, appropriate foundations for building public policies were specified and their political requirements were duly explained in detail.

There is nothing preventing these opportunities from being seized, except our own ability to establish a solid and persistent national strategy. Brazil can and must make progress in seizing these opportunities with ambition, realism, pragmatism, resilience, focus, and a long-term vision. For this purpose, a solid partnership must be established between the state and the private sector and legitimized by society around positive paths to be followed in the future.

The path of competitiveness has been established; respecting the specific features of competition in each market, a competitive company is and will always be an integrated, connected, and smart company. The future is built through investments in capacity-building and R&D, based on long-term plans tenaciously implemented on a daily basis.

The new technologies pave the way for Brazilian industry to develop skills and seize opportunities to compete, create new services, generate jobs, and contribute to improving the quality of life of our people.

INTRODUCTION

A changing world

Advancements in science and technology have induced a wave of combined and synergistic technological innovations with high disruptive potential. This wave has been transforming production patterns, business models, and forms of competition in advanced industrial economies, impacting consumption patterns and lifestyles. These impacts are compounded by the long-term trends of climate change, population aging processes, and the effects of globalization on social inequalities.

What are these innovation clusters with disruptive potential and how are they evolving? What do they mean for the future of Brazilian industry? How can their impacts on our production systems be analyzed? What kind of impact will they have on the productive and competitive situation of these productive systems? What are the challenges, risks, and opportunities involved?

These are the issues addressed in Volume 1 - “Disruptive Technologies and Industry: Current Situation and Prospective Analysis,” which opens the synthesis of the Industry 2027 project, *Building the Future of Industry*. This way, appropriate conditions are created for issuing public policy recommendations and providing inputs for private strategies, which are the subject of Volume 2 - “Disruptive Technologies and Industry: Challenges and Recommendations,” according to the terms of reference of the I2027 project.

The Industry 2027 project: field of studies

A changing world, the intensification of international competition, the emergence of innovation clusters with disruptive power, and the adoption of far-reaching national innovation strategies led CNI, through IEL and under the inspiration of MEI, to mobilize the Institute of Economics of the Federal University of Rio de Janeiro (UFRJ) and the Institute of Economics of the State University of Campinas (Unicamp) to carry out the project “Industry 2027: Risks and Opportunities for Brazil in the Face of Disruptive Innovations.”

The main objectives of the I2027 project are the following ones: (i) identifying trends and evaluating the impacts of disruptive technologies on major production systems over a five- to ten-year horizon; (ii) evaluating the capacity of Brazilian industry to deflect risks and seize opportunities afforded by disruptive innovations; and (iii) developing recommendations for the strategic planning of companies and inputs for public policy making.

The field of studies is that of technology clusters and production systems with a sectoral focus, as shown in Figure 1. The technologies were defined based on their disruptive impacts and they were organized into eight clusters grouped according to similarities between their respective technical bases. Industry was organized into ten production systems and 14 sectoral foci selected according to their economic importance in the country's industrial matrix and to the potential impact of innovations on each of them.

Figure 1 – Field of studies of the Industry 2027 project

PRODUCTION SYSTEMS	SECTORAL FOCI
Agroindustries	Processed Food Products
Basic Inputs	Steelmaking
Chemicals	Bioeconomy
Oil and Gas	Deepwater Exploration & Production
Capital Goods	Agricultural Machinery and Implements, Machine Tools, Electric Engines, Energy Generation, Transmission and Distribution Equipment
Automotive Complex	Light Vehicles
Aerospace, Defense	Aeronautics
Information and Communication Technologies	Telecommunications Systems and Equipment, Microelectronics, Software
Pharmaceuticals	Biopharmaceuticals
Consumer Goods	Textiles and Wearing Apparel

Source: Prepared by the I2027 project team.

The technology clusters are the following ones: Artificial intelligence, Big Data, Cloud Computing; Internet of Things, their systems and equipment; Smart and Connected Production (advanced manufacturing); Communication Networks; Nanotechnologies; Advanced Bioprocessing and Biotechnologies; Advanced Materials; and new Energy Storage technologies.

The production systems and their respective sectoral foci are the following ones: Agroindustry, with a focus on Processed Food Products; Basic Inputs, with a focus on Steelmaking; Chemicals, with a focus on Bioeconomics; Oil and Gas, with a focus on Deepwater Exploration and Production; Capital Goods, with a focus on Agricultural Machinery and Implements, Machine Tools, Electric Motors, Energy Generation, Transmission and Distribution Equipment; Automotive Complex, with a focus on Light Vehicles; Information and Communication Technologies, with a focus on Telecommunications Systems and Equipment, Microelectronics and Software; Pharmaceuticals, with a focus on Biopharmaceutical Products; Consumer Goods, with a focus on Textiles and Wearing Apparel.

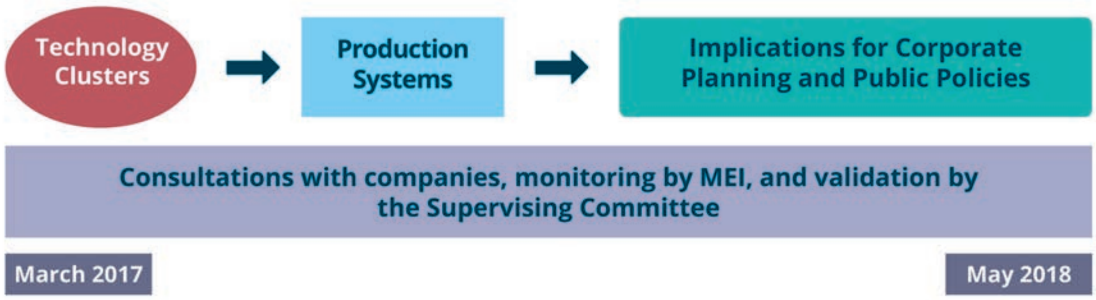
Two warnings should be made at this point. First, this project mainly considered technological solutions that could be commercially available by 2027. Solutions that may only become available in a longer term were not analyzed in depth. Second, changes that technical progress will bring about in other dimensions of economic and social life were not directly considered. Impacts on consumption patterns, on economic regionalization, or on the labor market and occupations, for example, were only considered when deemed relevant to the competitiveness of companies.

Development of the Industry 2027 project and the structure of this publication

During a 14-month period, from March 2017 to May 2018, a team of 75 experts of recognized competence in technologies, industrial sectors, and innovation policy was mobilized in Brazil and abroad to contribute in one of the stages of the Industry 2027 project. Representatives from approximately 750 companies were consulted in a field survey about the current stage and prospects of digitization in their companies.

The development of the Industry 2027 project was monitored by MEI at all meetings of leaders and some MEI Dialogue sessions. A supervisory committee monitored its implementation and defined strategic guidelines; teams made up of CNI, IEL, and SENAI experts submitted documents for technical analysis and ensured the project's timely implementation. These are the main assets of the I2027 project: the knowledge and competence of well-informed and specialized professionals.

Figure 2 – Development stages of the Industry 2027 project



Source: Prepared by the I2027 project team.

As shown in Figure 2, the Industry 2027 project was implemented in three sequential steps: prospective study of technology clusters; analysis of production systems and their sectoral focus and conduction of the field survey; and definition of implications for public policies and entrepreneurial strategies. The results were compiled into two summarized volumes, one of an analytical and diagnostic character and a second one of a propositional nature. This is volume 1, the results of which are shown below.

Prospective evaluation of technology clusters

The first stage of the I2027 project consisted in a prospective evaluation of eight technology clusters in the world economy and in Brazil. The following topics were evaluated: (i) identification of the main disruptive technologies being developed in each technological cluster and definition of the expected time horizon for them to be actually used by industrial companies, with a focus on a ten-year time horizon until 2027; and (ii) identification of production systems and sectoral foci most potentially impacted by the actual adoption of innovations resulting from the identified developments.

Each technological cluster was evaluated by an expert with extensive working experience in research institutes and/or companies. With the aim of expanding the knowledge scope and ensuring the quality of the evaluations, the work of these specialists was reviewed by an ad hoc group of specialists in two rounds of working meetings moderated by the project coordination team. The full team of experts involved in this step is described in Appendix 1.

The knowledge generated by the experts in the process of analyzing the clusters were compiled by the technical coordinators of the I2027 project in a document entitled *Map of Technology Clusters*, which proposes an analytical framework for evaluating the evolution of the clusters identifying relevant technologies for the competitiveness of production systems, in addition to specifying *Expected Impacts of Clusters on Production Systems*. This prospective assessment is summarized in Chapter 1 of this volume, entitled "Technology Clusters: what are they, how do they evolve, and what impacts can potentially disruptive innovations bring about?".

Analysis of impacts on production systems and sectoral foci

The prospective evaluation of clusters produced inputs for the following stage of the I2027 project, in which the impacts of innovations on selected production systems and sectoral foci were analyzed. Industry was evaluated in two parallel ways: (i) by conducting a field survey on the current and expected digitization of Brazilian industry; and (ii) by carrying out a prospective analysis of disruptive impacts on production systems and sectoral foci.

The field survey was intended to investigate which digital technologies are being used today and which ones are likely to be used in the near future and it distinguished between four digitization generations (G1, G2, G3 and G4), ranging from isolated digitization (G1) to integrated, connected, and smart companies (G4). Representatives from approximately 750 companies reported the stage in which their companies were in 2017 and where they expect them to be by 2027, how their companies are preparing for the future, and the likelihood of the most advanced generation becoming dominant in the sectors in which their companies operate.

This analysis provided an overview of the current and expected stage of digitization of Brazilian industry and paved the way for a detailed and careful analysis of the impact of new technologies on the different production systems and sectoral foci. The results of this analysis can be found in Chapter 2, entitled "The Digitization of Brazilian Industry: where are we now and where are we headed?"

The prospective analysis of the ten production systems and their sectoral foci was carried out by sectoral experts, who evaluated the following aspects: (i) the economic and competitive dynamics of production systems and sectoral foci in the world and in Brazil; (ii) the process of generating, using, and disseminating relevant technologies in the production systems and sectoral foci analyzed, both in the world and within Brazil; and (iii) challenges, risks, and opportunities for Brazilian industry. The full list of the sectoral experts who worked in this stage of the project can be found in Appendix 1.

The results of the analysis of production systems were organized into ten sectoral technical notes and then compared and systematized by the I2027 project technical coordination team. This systematization was intended to group the productive systems (and their sectoral foci) into four categories of sectors based on the criterion of similarity of function or nature of the activities that they carry out in the economy. The productive systems were thus grouped into: (i) sectors that disseminate innovations; (ii) sectors of specialized activities and advanced knowledge; (iii) sectors that produce intermediate inputs; and (iv) sectors that supply consumer goods.

Brief summary of the groups of sectors

Chapters 3 through 6 of this volume analyze potential impacts of new technologies and identify key challenges for industry to remain competitive, avoid setbacks, and take advantage of windows of opportunity. These are the following ones: "Sectors that Disseminate Innovations" (Chapter 3), "Sectors of Specialized Activities and Advanced Knowledge" (Chapter 4), "Sectors that Produce Intermediate Inputs" (Chapter 5), and "Sectors that Supply Consumer Goods" (Chapter 6).

In the case of the **sectors that disseminate innovations**, the main challenge is to keep up with the international production frontier and to explore synergies with competitive demanding sectors. The two production systems that disseminate innovations are the ICT and Capital Goods (BK) sectors, respectively. Relevant segments in these two systems can seize opportunities afforded by the Internet of Things (IoT) and manufacturing digitization. To a large extent, these processes require customized solutions, a fact that opens up windows of opportunity for both ICT and BK integrating companies. In addition, internationally competitive sectors (such as the agribusiness sector) are already demanding the adoption of these solutions. The challenge is therefore that of stimulating companies to seize opportunities on the solution supply side, while meeting other relevant demands of today's market. If this challenge is not addressed satisfactorily, the development of competitive sectors in our economy will be slowed down.

Windows of opportunity for **specialized activities and advanced knowledge** make it possible for these sectors to evolve along with the international technological frontier. This group includes the production systems of the Aeronautics and Defense, Pharmaceuticals, Bioeconomics and Deepwater Oil and Gas Exploration sectors. These are niches for knowledge-intensive activities in which Brazil has innovation ecosystems with the minimum required capabilities and competitive leading companies capable of creating positive conditions for these windows of opportunity to be seized.

Producers of intermediate inputs play a significant role in Brazilian industry and have already proven to be competitively and productively efficient to keep up with the global productivity frontier. The steelmaking, commodity processing, pulp production, petroleum refining and petrochemicals industries are capital-intensive sectors that have accumulated economies of scale and productive synergies that make it possible for them to compete successfully in their respective world markets. In the face of disruptive innovations, these sectors will need to digitize their respective value chains if they are to keep up with the productivity frontier and strengthen their innovation ecosystems to explore possibilities for differentiating their products.

Consumer goods sectors, which also play a prominent role in Brazilian industry, are made up of heterogeneous companies that, with exceptions, have been lagging behind on the frontier of productive efficiency and product technologies. The durable goods industry (automobiles, home appliances, small appliances) is dominated by subsidiaries of transnational corporations that, in theory, could be moving faster toward adopting new, efficient, and smart product technologies. In semi-durable goods sectors, such as in those of textiles, wearing apparel, and footwear, the heterogeneity in terms of technological capacity and competitiveness is substantial. The non-durable goods industry, especially that of processed and industrialized food products, is also characterized by substantial heterogeneity in technical capacity. Therefore, the main challenge for the Consumer Goods industry lies in making a significant and continuous effort to adopt new digital technologies in the areas of production, value chain integration, management, trading, marketing, design, digitization, and product quality.

Legacies and challenges of Brazilian production systems as a starting point

Given the likely impacts of new technology clusters over the next ten years, this Volume 1 sought to systematize a diagnosis of the situation of the main production systems of Brazilian industry in the face of these potentially disruptive innovations. It also provides an unprecedented and valuable overview of the stages of adoption of advanced digital manufacturing technologies by Brazilian industry, including the plans and expectations of the representatives of companies consulted in the field survey.

This analysis made it possible for the technical coordinators of the I2027 project to group production systems and their respective sectoral foci into four groups sharing similar economic functions, capabilities, and challenges, with a view to facilitating the definition of recommendations for public policies and inputs for private strategies - topics that will be addressed in Volume 2.

1

TECHNOLOGY CLUSTERS: WHAT ARE THEY, HOW DO THEY EVOLVE, AND WHAT IMPACTS CAN POTENTIALLY DISRUPTIVE INNOVATIONS BRING ABOUT?

1.1 How can technological changes be analyzed?

Academics, consultants, research institutes, government and non-government organizations, and the media in general have been reporting the emergence of a new technological revolution (the fourth or fifth one, depending on the periods of major changes in the past they refer to). In the manufacturing world, the changes taking place are referred to as Industry 4.0 or Advanced Manufacturing. The I2027 project is not intended to engage in conceptual discussions or to challenge characterizations; its focus is clear: evaluating how technical progress impacts on business models, competition patterns, and market structures in industry.

What industry-relevant technologies are being developed and will become commercially available in the world over a five- to ten-year horizon? What are the constituent characteristics of these technologies? Is it possible to determine common paths of evolution in terms of costs and markets? Are these innovations actually disruptive, or rather, when will the impacts of these innovations on different production systems of industry be disruptive? Are the generation, use, and diffusion of innovations associated with risks and constraints? These were the questions that guided the prospective analysis of technologies organized into clusters of the I2027 project.

Economically relevant technologies were grouped into eight technology clusters according to the degree of similarity and specialization of their knowledge bases: artificial intelligence, big data, and cloud computing (AI); Internet of Things (IoT); communication systems, equipment, and networks (Networks); smart and connected production (SCP); advanced bioprocessing and biotechnologies; nanotechnology; advanced materials (AMs); and energy storage (ES).

Six analytical categories were used to characterize technology clusters, including categories describing the nature and dynamics of technical progress and categories linking technical progress and industrial activities (Graph 1).

Graph 1 – Concepts for technological evaluation and prospection

CHARACTERIZATION	SPECIFICATION	CATEGORIES
FOR DESCRIBING TECHNICAL PROGRESS		
TYPE OF INNOVATION	Defines where innovation manifests itself	In processes; products; organizational models; markets; inputs
STAGE OF DEVELOPMENT	Determines whether rules and standards can be determined already	**Mature:** Established technological standard
		Under selection: technical standards in competition
		Undergoing changes: solutions are still under development
INTENSITY OF THE TECHNOLOGICAL CHANGE	Establishes the degree of innovativeness of a technology	**Incremental** **Radical**
RELATIONSHIP BETWEEN TECHNOLOGIES	Defines the extent to which a technology enables others	**Widespread** **Localized**
FOR DESCRIBING RELATIONSHIPS BETWEEN INNOVATIONS AND PRODUCTIVE ACTIVITIES		
SPECTRUM	Defines the scope of application to different economic activities	**General Purpose**
		Purpose or application in specific activities
IMPACT	Influence on business models, competition patterns, and market structures	**Moderate**
		Disruptive
		Potentially disruptive

Source: Prepared by the I2027 project team.

1.2 Map, trajectories, and characterization of technology clusters

1.2.1 Convergent, integrated, connected, smart innovations

Technology clusters provide convergent, integrated, connected, and increasingly smart innovations. They are convergent because they do not emerge and develop in isolation, but rather in synergy with other innovations, including with those stemming from other knowledge bases; they are integrated because they are increasingly linked to the various steps involved in generating products; they are connected because organizations, processes, and even products communicate autonomously with each other through high-speed digital networks and capacity; they are smart because products, processes, and components incorporate cognitive capacities and carry solutions in themselves, not only through artificial intelligence, but also in their own make-up, like some advanced materials that can "reshape" themselves when they undergo changes, for example.

Graph 2 shows in detail the constituent elements of integrated, connected, and smart innovations in the form of a map of technology clusters.

Graph 2 – Map of technology clusters

ANALYTICAL CATEGORIES	ARTIFICAL INTELLIGENCE, BIG DATA, CLOUD (AI)	COMMUNICATION NETWORKS (NETWORKS)	INTERNET OF THINGS (IOT)	SMART AND CONNECTED PRODUCTION (SCP)	ADVANCED MATERIALS (AMS)	NANOTECHNOLOGY (NANO)	BIOTECNOLOGY (BIO)	ENERGY STORAGE (ES)
TYPES OF INNOVATIONS	Product, processes, inputs, organizational, infrastructure, and market	Product, infrastructure, and market	Product, processes, inputs, organizational, infrastructure, and market	Process, organizational, and markets	Products, inputs, and markets	Products, inputs, processes, and markets	Products, inputs, processes, and markets	Product, process, and market
STAGE OF DEVELOPMENT	Technologies undergoing changes prevail	Mature technologies and technologies under selection coexist	Technologies undergoing changes prevail	Mature technologies and technologies under selection coexist	Mature technologies and technologies under selection and undergoing changes coexist	Technologies under selection and undergoing changes coexist	Mature technologies and technologies undergoing changes coexist	Mature technologies and technologies under selection coexist
INTENSITY OF THE TECHNOLOGICAL CHANGE	Incremental with radical potential	Incremental prevails	Incremental with radical potential	Incremental with radical potential	Incremental prevails	Radical prevails	Incremental with radical potential	Incremental prevails
CONTRIBUTION OF THE CLUSTER TO OTHER CLUSTERS	General: IoT, NETWORKS, SCP, AMs, NANO, BIO, ES	Localized: AI, IoT, SCP, ES	General: AI, NETWORKS, SCP, AMs, NANO, BIO, ES	Localized: AMs, NANO, BIO	Localized: NETWORKS, NANO, ES	General: IoT, NETWORKS, SCP, AMs, BIO, ES	Localized: AMs, NANO	Localized: IoT, NETWORKS, SCP
SPECTRUM	General purpose	General purpose	General purpose	Specific purpose: industrial processes	Specific purpose: equipment	General purpose	Specific purpose: human, industry, agriculture	Specific purpose: autonomous electrification and energy conservation
IMPACT	Disruptive potential prevails until 2027	Coexistence: moderate and disruptive potential until 2027	Disruptive potential prevails until 2027	Disruptive potential prevails until 2027	Coexistence: moderate, disruptive potential and disruptive	Disruptive potential prevails until 2027	Disruptive	Moderate prevails

Source: Prepared by the I2027 project team.

This map shows that most innovations developed in clusters are broadly reflected in products and processes, leading to organizational changes in companies and opening new market perspectives. Technologies with mature solutions, in the process of being selected, and undergoing changes coexist with each other in clusters. Digital technologies, for example, have been available since 1971, using the year in which microprocessors became commercially available as reference, and their processing power has doubled at 18-month intervals since then (Moore's Law). The challenges involved in processing high volumes of information, however, require alternative and more powerful solutions that are already entering experimental mode, indicating major changes in the microprocessor industry itself. Quantum computing, for example, has such a high processing power that it makes possible to develop approximation-free simulation models, which cannot be done with the latest-generation microprocessors in supercomputers.

Integration and interaction between clusters has multiplied the emergence of innovations in production and management processes, inducing changes with disruptive potential in business models and competition patterns, such as the trend toward servitization.

The intensity of technological change in each cluster is predominantly incremental: new generations of innovations are constantly emerging in evolutionary processes. However, their cumulative effect can be considered as radical, since when certain levels of efficiency/cost are reached, powerful effects of change are triggered.

Digital technologies and nanotechnologies are functional and enable the development of the remaining clusters. These are broad-spectrum technologies that can be applied to any industrial activity, particularly to those associated with information technology-intensive clusters. The exceptions are biotechnologies, advanced materials, and energy storage technologies for specific sectoral applications, such as those for use in the drug-health care, chemicals, and agroindustrial sectors; in the oil and gas and consumer goods sectors; and in the capital goods and automotive sectors, respectively.

The predominant impact until 2027 is disruptive: until then, significant changes in business models, competition patterns, and possibly market structures are expected. A detailed analysis of impacts will be provided later here.

1.2.2 Usefulness and potential of new technologies

a) Artificial intelligence, Big Data and Cloud Computing
In general terms, artificial intelligence (AI) can be used in cyberphysical systems for processing and making automated, decentralized, and autonomous decisions. It is associated with the development of mathematical and statistical algorithms and computing technologies inspired by the way the human brain works and uses the nervous system to feel, communicate, learn, reason, and act. By applying algorithms, these technologies use structured databases for computers and other equipment items to accumulate learning and cognition that enable them to make decisions. AI Applications can produce radical effects on processes, products, inputs, organizations, infrastructures, and markets. These technologies are at various stages of development, but in these stages the pace of technical progress is very intense and of general application (in industry), enabling other technologies.

b) Communication networks
A communication network is an interconnected system of computers, transmission technologies, and related resources used for processing, exchanging, or disseminating information. Modern telecommunications networks adopt the Internet protocol(IP) and their comprehensive digitization has made it possible for the Internet to emerge as a large and increasingly ubiquitous global integrating network involving a wide range of communication, processing, and computing devices. The main innovations achieved in specific communication networks are related to product innovations (product-embedded networks or connected products) and infrastructure innovations (networks as platforms for intra-firm and extra-firm integration or for urban infrastructures or grids), resulting in new markets. Communication networks can be used in industry in five ways: networks

in end products, networks directly embedded in a product (aircraft), and product aggregation (traceability); networks in production processes (oversight, control, activation); networks in the organization of a company; networks in the organization of the production chain; networks in a product life cycle (product monitoring).

c) Internet of Things

The Internet of Things (IoT) consists in the interconnection, through the Internet, of computer network access devices embedded into machines, equipment, and everyday objects, allowing them to send and receive data. Distributed microelectronic sensors and gateways make up information collection and processing systems that can be centralized and processed in the cloud or in specialized servers. This set of subsystems is a component of any IoT solution. IoT is expressed in processes in which machines, different equipment items, and devices are connected and capable of performing management tasks that optimize productive units and infrastructures, improve the predictive maintenance of machines, activate connected and smart home appliances, and support the management and organization of logistic chains and the monitoring of clients who are users of connected products. These are technologies that enable innovations in other clusters and we are not talking about already known technologies only, but also about new generations of technologies in the making. However, uncertainties still prevail regarding interoperability, technical communication standardization, and data security. Although IoT innovations have initially emerged as incremental innovations, they have the potential to become radical innovations depending on technological convergence (combinations with technologies developed in other clusters) and on how these technologies are used in each production system.

d) Smart and connected production

Smart and connected production (SCP) refers to cyberphysical systems for digital interconnection, through the Internet, of productive units and their respective upstream and downstream value chains, with increasing use of artificial intelligence. Among the main hard-core technologies in use and under development, special mention must be made of those related to additive manufacturing, autonomous and collaborative robotics, and advanced software for online integration and digitization of production through a network of sensors, processors, and actuators embedded in machines and equipment and integrated by servers.

So far, no dominant standards have established themselves and therefore there are high architectural uncertainties as to the ability of machines to incorporate advanced cognitive capabilities made possible by advancements in AI, to the adaptability of different links in the value chain, and also to the legacy of old-generation machines; and as to the "war" of standards (proprietary versus open source).

SCP will make room for a more intense interaction between the physical and virtual world that will result in new business models. Instrumental technologies associated with SCP can be incorporated into any productive activity and its potential for inducing change is very significant, as applying it leads to increased: flexibility, quality, and efficiency of production systems; vertical integration of actuators and sensors under enterprise resource planning (ERP) software; degree of project and design freedom; speed, efficiency, and collaboration between companies, regardless of their geographic location. In addition, SCP will provide reconfigurable manufacturing systems and plant model diversity, with solutions tailored to specific market characteristics, product life cycle optimization, and specifically customized products and services.

e) Advanced Materials

Advanced materials (AMs) are those that add new characteristics to traditional materials or new materials with superior performance in one or more characteristics of their commercial application. Historical experience shows that the maturation period of advanced materials is long; advancements in these materials depend on scientific and technological innovations combining affordable, non-toxic, and manufacturable raw materials at competitive scale and costs. AMs can be divided into five groups: nanomaterials, self-repairing and/or functional materials, high-performance materials, materials from renewable sources, and products resulting from the biorefinery of rare earths.

These are materials for broad use and specific applications, such as, for example: functional and "smart" packaging and structures (for example, self-repairing, fungicidal/bactericidal, self-increasing, thermal sensitive items, etc.); resistant structures (mechanical and thermal items) and/or light structures (high-performance materials); materials for controlled release of compounds (in humans and animals or in the environment); materials for electronic circuit printing and additive printing (3D printing) ; bioinspired, biomimetic, and biodegradable materials (i.e. materials with properties similar to those of natural materials and/or materials from renewable sources/substitutes for fossil materials); permanent magnets (for use in vehicle and industrial engines).

f) Nanotechnology

Nanoscience and nanotechnology are fields of science and technology that deal with matter at the nanoscopic scale (less than about 100 nm in at least one of its dimensions) and that apply concepts and materials produced based on such studies. Nanotechnologies are in a transition from "active nanostructures" used in electronics, sensors, objective drugs, and adaptive structures to "nanosystem systems" such as 3D nanonetworks in robotics, supramolecular structures, and guided molecular assembly. Nanotechnologies impact and modify processes and forms of business organization and therefore they require new competencies.

They can be applied to all production systems, such as to those related to nanomedicine (diagnosis, therapy, and "theranostics") and nanocosmetics; nanoelectronics and new computing materials; wearing apparel and flexible and wearable devices; IoT sensing; energy as an ancillary technology; and food as an enabling technology to ensure food security and nanofood. The main areas for application of nanotechnologies in the coming decade include, particularly, nanomedicine and nanocosmetics (vaccines, nanomaterials for implants); nanoelectronics and new computing materials (application in quantum computing as well as in nanofabrication of these structures); wearing apparel and flexible and wearable devices; IoT sensing (sensors and actuators, built with nanomaterials); nanotechnology for energy (new materials for batteries); food nanotechnology (traceability for food security; precision agricultural sensors; food processing).

g) Biotechnology

Biotechnology involves a set of intervention techniques in the genome of living organisms or their parts to obtain or modify products, improve plants or animals, or develop microorganisms for specific purposes. Contemporary biotechnology, whether vegetable, animal, industrial, or human biotechnology, depends on: "omic" technologies, such as genomics, transcriptomics, proteomics, and metabolomics; bioinformatics; and on a set of advanced molecular and cellular manipulation techniques. Biotechnology is usually separated into three main types of biotechnological development areas, each of which has a specific scope: (i) red biotechnology, applied to human and animal health; (ii) green biotechnology, applied to agriculture and food production; and (iii) white biotechnology, applied to industrial processes.

Biotechnology clusters generate product innovations that require process innovations and new inputs, opening new markets. These are clusters with applications focused on specific production systems: medicine and health, agroindustries, and chemicals. Because they modify the technical knowledge base for traditional drugs, biotechnologies can also imply organizational changes in pharmaceutical companies intending to use them.

In terms of stage of development, the genome sequencing technology is already considered mature. Gene editing technologies and advanced cell manipulation technologies (stem cells), which are seen as disruptive, are under development currently and subject to mutations. The recent emergence (in 2015) of the CRISPR/Cas9 technique (clustered regularly interspaced short palindromic repeats - CRISPR / associated nuclease protein - Cas9) represented a qualitative leap by making gene editing much more efficient. By making it possible to "cut and paste" genes from immune cells involved in protecting organisms, CRISPR/Cas9 quickly surpassed other existing genetic editing tools.

The combination of genomic, molecular biology, and bioinformatics technologies created new paradigms in their respective areas of application. In the medical field, it led to the development of "customized precision medicine." In agriculture, these innovations have been applied to crops such as rice, corn, soybeans, and wheat, speeding up the transition to precision agriculture. By making it possible to improve plant genomes without introducing exogenous gene sequences, gene editing differs from transgenic techniques and is therefore less subject to regulatory constraints. Gene editing for animals will play a significant role in the coming decades, especially due to the possibility of allelic reconstruction, based on large-scale sequencing, and of mapping out promising alleles in genetically diverse populations. Sequencing of more rustic populations better adapted to tropical conditions is also expected. This information will likely contribute to identifying orthologous genes that will serve as the basis for gene editing in elite matrices.

Genome editing is expected to lead to deep changes in a wide range of economic activities. Mastering it requires high investments in terms of finance and human resources and its regulatory implications are yet to be defined. Corn hybrids with high amylopectin content as a result of gene editing have already been authorized for marketing in the US without the need to comply with the legislation on transgenic plants. This precedent may lead to the rapid arrival in the market of plants with alleles edited not to contain DNA fragments from other species and/or major changes in the endogenous DNA sequence. In addition to regulatory aspects, possible intellectual property scenarios may result in broad, non-exclusive access to the technology and, consequently, to participation in the market of several research institutions and companies that may introduce new plant genotypes and alleles produced by genome editing.

h) Energy Storage

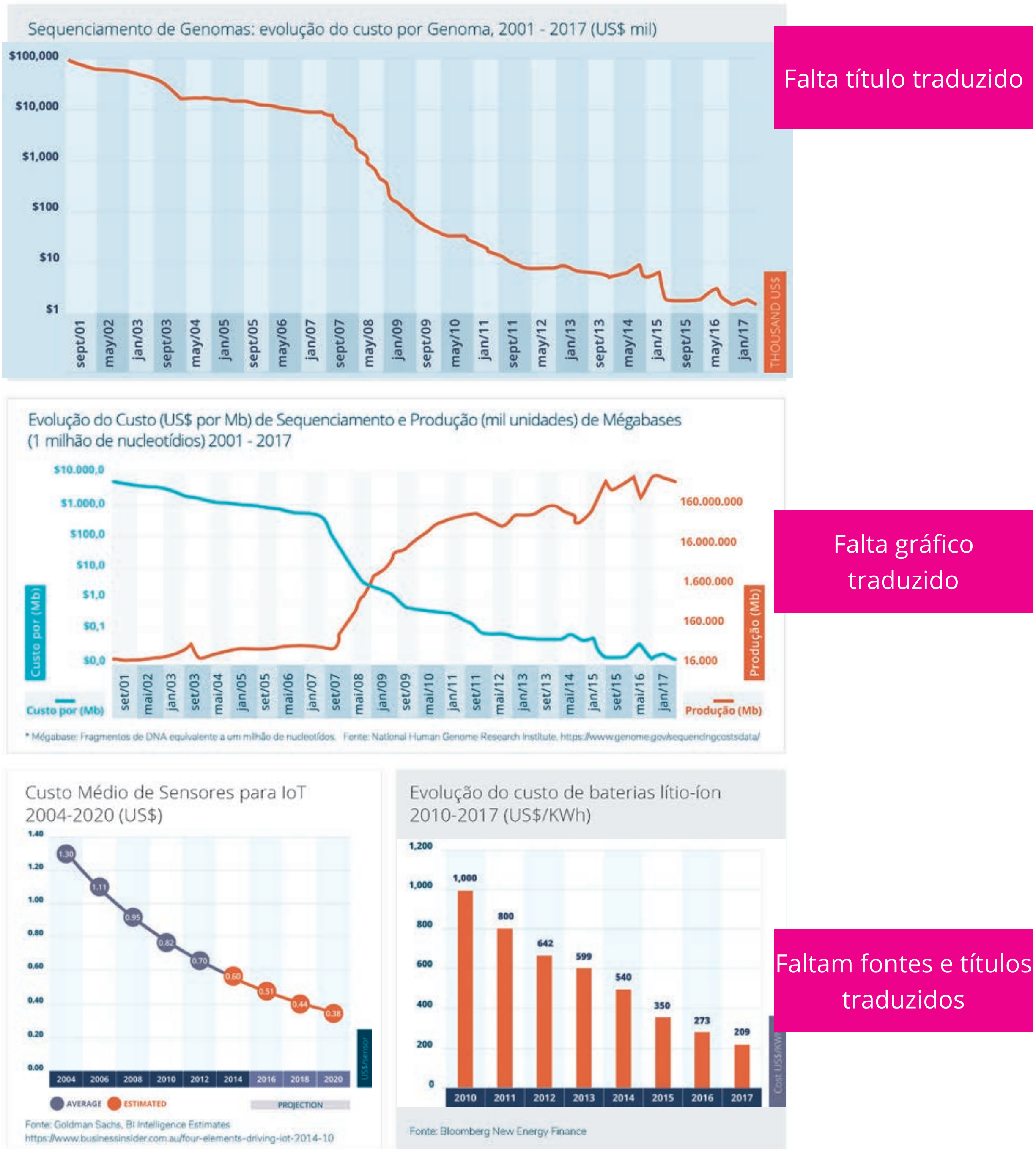
Electrochemical energy storage (ES) refers to using a chemical reaction (redox reaction) to store electricity. The progress made in the field of electrochemical technologies and methods for energy storage has been relatively slow. Energy storage solutions result in products that can be used as inputs for other products or as products in themselves in industrial processes. Applications of ES technologies are specific for electrification of production systems or autonomous products and for energy conservation purposes. ES innovations (especially batteries) are instrumental for IoT innovations (e.g. portable connected devices, drones), networks (energy supply or energy security for large servers) and for supplying power to autonomous production systems.

Mature technologies and technologies being considered for selection coexist in this cluster. These mature technologies include particularly lead-acid batteries, portable batteries (lithium-ion batteries), and fuel cells (which are scientifically and technologically mature, but face bottlenecks that prevent their dissemination in the economy). With the rapid development of the science of materials, research is underway on new graphene-based energy storage technologies. ES technologies can be used for three main purposes: to ensure the autonomy of systems in relation to the electricity grid; to electrify products and processes that used to be dependent on fossil fuels; to ensure the security of energy matrices. Such uses depend on technical variables: portability (power/weight ratio); recharge duration; nominal and actual maximum power; and safety of use. The higher these variables, the greater the potential for use and disruptive impact: the lower the cost, the greater the sustainability (energy) and the greater the disruptive power.

1.2.3 Falling costs, expanding markets: the convergent and increasing economic importance of technology clusters

Declining costs and fast-growing markets characterize recent and expected developments and reveal the economic importance of innovative solutions and products in all clusters. Graphs 3 and 4 present projections for various technologies and products from various sources, all of which point in the same direction.

Graph 3 – Costs of new technologies and products: recent developments and projections



Source: Compiled by the I2027 project team.

The sharpest drops in costs were those recorded in the cost per megabits and in genome sequencing costs. Sequencing costs in 2001 amounted to US$100 million; in 2007, they dropped to US$10 million; in July 2017, they fell to US$1,000. At this rate, costs will likely amount to US$1.00-US$0.01 per genome in 2020. The cost per megabits amounted in turn to US$5,000 in 2001; then it dropped to US$500 in 2007; and in July 2017 it fell to US$0.012.

Graph 4 – Markets for new technologies and products: recent developments and projections

YEAR	INDUSTRIAL	MILITARY	PERSONNEL	COMMERCIAL
2000	3.9	2.4	1.1	0.0
2005	5.2	3.5	0.4	1.7
2010	5.8	5.1	1.0	3.2
2015	11.0	7.5	2.5	5.9
2020	16.4	11.2	4.5	10.8
2025	24.4	16.5	9.0	17.0

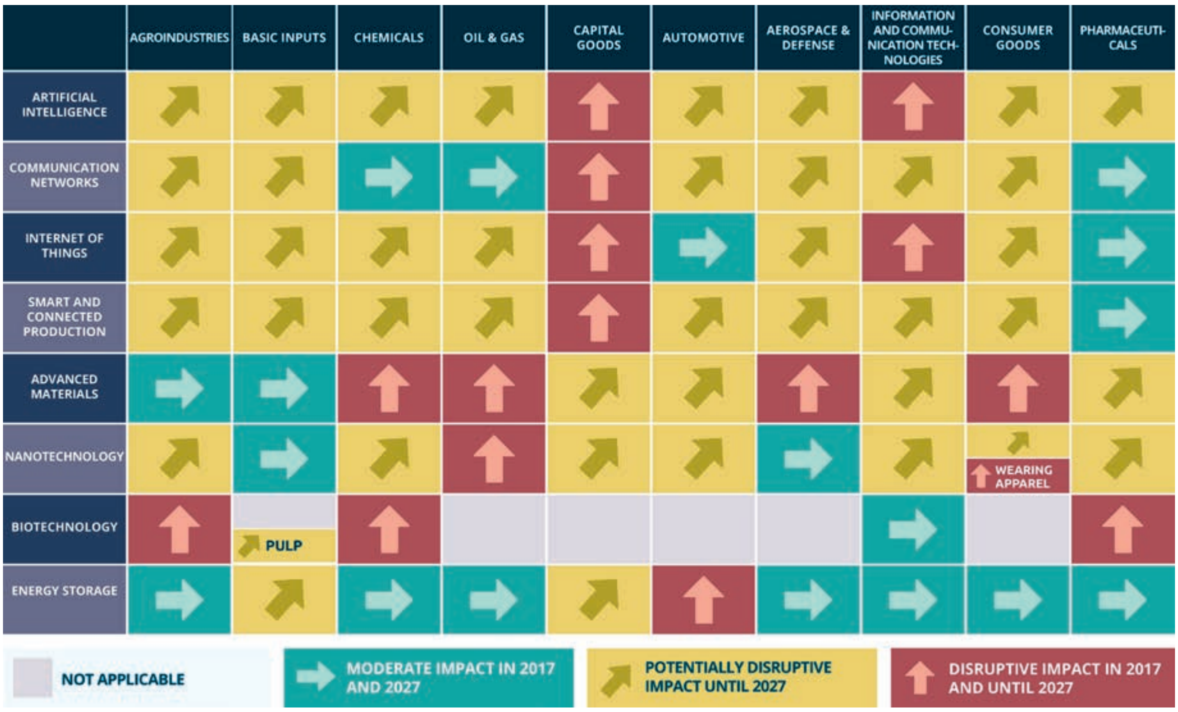
Source: Compiled by the I2027 project team.

In the field of digital innovations, expenditures on artificial intelligence systems are projected to amount to approximately US$46 billion in 2020. In that year, the sales value of big data may rise to US$57 billion and hit the mark of US$92 billion in 2026, representing a growth of almost 100%. The average cost of sensors for IoT has been falling rapidly: from US$1.30 in 2004, it may decline to US$0.38 in 2020. By 2020, the 3D printing market could reach US$21 billion. The robotics market for different applications has in turn been increasing rapidly, from US$7.4 billion at the turn of the 20th century to US$26.9 billion in 2015, and it is likely to grow to US$63,9 billion in 2025. For industrial applications alone, the robotics market may increase to US$24.4 billion this year. The nanotechnology market has been following a similar trajectory: in 2015 it was estimated at US$27 billion and by 2020 it is expected to hit the mark of US$76 billion. Different projections for the costs (US$/kWh) of lithium-ion batteries for automobiles point to costs between US$400 and US$200/kWh in 2020 and to declining costs in subsequent years.

1.2.4 Impacts of relevant technologies for the competitiveness of productive systems

Graph 5 summarizes the main impacts of innovations associated with each technology cluster on each production system.

Graph 5 – Impacts of technology clusters on production systems



Source: Prepared by the I2027 project team.

Clusters generally associated with digital technologies usually generate similar (potentially disruptive) impacts on different production systems. Artificial intelligence, IoT, and SCP are the clusters that will be generating potentially disruptive impacts until 2027 for a greater number of production systems, depending on specific technological developments and on how specific technological bottlenecks are addressed. Clusters related to advanced materials and biotechnology (where applicable) are those that are already generating, in 2017, disruptive impacts on productive systems. However, advanced materials also have an impact on other systems in a moderate and potentially disruptive way, depending on the field of the materials in question and on their applications. The energy storage cluster generates a greater number of moderate impacts on production systems, except on the Automotive sector and (potentially) on Basic Inputs and Capital Goods systems.

Each productive system is impacted differently by technological innovations developed by the eight clusters and all systems are facing at least one already disruptive process in 2017. The exception, in this case, is that of the Basic Inputs system, where potentially disruptive impacts prevailed until 2027, except for those derived from innovations in advanced materials and nanotechnologies, which tend to optimize this system's production. The Chemicals, Petroleum and Gas, and Capital Goods systems are already facing disruptive impacts from advanced materials and biotechnology (Chemicals), advanced materials and nanotechnologies (Oil and Gas). However, Capital Goods is the system facing disruptive impacts in 2017 from all digital clusters, while the one that will have the most moderate impacts is that of Pharmaceuticals. However, the biotechnology cluster, which plays a key role in the drug production system, is already bringing about disruptive impacts, paving the way for changes in business models, competition patterns and, possibly, market structures.

Albeit in different ways, given the disparate characteristics of these production systems, the Aerospace and Defense and Consumer Goods systems are facing similar impacts in terms of the origin of the innovations. In the short term, disruptive impacts emerging only from the advanced materials cluster will be felt. Although the Aerospace and Defense system is already adopting some AM technologies, major changes are likely in how aircraft projects are developed, creating opportunities and challenges for manufacturers of aircraft and aerostructures. In the case of Consumer Goods, the impact of nanotechnologies is potentially disruptive. In both systems, the impacts of ES tend to be moderate.

Only the ES cluster has disruptive impacts in the short term on the Automotive system, while only the IoT cluster has a moderate impact on it. The other clusters have generated potentially disruptive cumulative impacts until 2027: AI, networks, SCP, AMs, and nanotechnology. In the case of AI technologies, for example, disruptive impacts could be brought about by the diffusion of autonomous cars and car-sharing, which would change a pattern of consumption focused on individual property.

In the Agroindustrial sector, biotechnology has disruptive impacts in the short term, while ES and AMs generate moderate or optimizing impacts on production. The remaining clusters generated potentially disruptive cumulative impacts on Agribusiness until 2027: AI, networks, IoT, SCP, and nanotechnologies.

The ICT system has already been facing disruptive impacts from AI and will potentially face disruptive cumulative impacts from four others clusters by 2027: networks, SCP, AMs, and nanotechnologies. For the ICT system, the impacts of biotechnology and ES have been moderate.

1.3 Warnings

1.3.1 Warnings for Industry

Converged, integrated, connected, and smart innovations will change how companies organize themselves and the key drivers of competitive success. There is no certainty as to whether companies with a large market share today will continue to enjoy this status over the next ten years.

Technologies at various stages of development, in addition to technologies changing at a rapid pace, coexist in the clusters at large. Many of the solutions have not been standardized, as alternatives are yet to be selected and others are still undergoing changes. Technologies being considered for selection and those undergoing changes add unpredictability to technical progress and business decision making. In uncertain environments, adopting a first mover strategy, if successful, can lead to higher profit margins. However, this is not always the most efficient and effective strategy vis-à-vis fast follower strategies, which would not be burdened with trial and error costs until new solutions become fully efficient. Regardless of the strategy adopted, the message from the ongoing transformations is very clear: for opportunities to be seized and risks deflected, innovation strategies must be at the heart of competitive strategies.

What is referred to as the fourth or fifth technological revolution will not occur in the short term, but rather with time. The ten-year horizon of the I2027 project seems to be long. But it isn't. New technologies will be disseminated at an increasing pace, considering that the decline in the costs of key technologies in all clusters is very sharp. The cumulative processes of generating and disseminating new technologies and their synergy or combination will lead to deep changes in ways of doing business.

However, as the diffusion curve of new technologies (worldwide) is on the upswing, access barriers are still low and opportunities are available for strengthening the competitiveness (or survival) of companies that take proactive innovative actions. Proactive strategies mean adopting and absorbing innovations, investing in learning and training, and building competencies consistent with each company's "genetic code."

Windows of opportunity for absorbing key technologies are still widely open. Solutions are flexible enough to be introduced gradually, without the need to cannibalize existing fixed assets. For example, it is possible to "sensorize" machines and equipment from previous technological generations. However, new technologies are not developed or used in isolation, but rather in blending with others. Investing in isolated technologies is counterproductive: it would be unreasonable to invest in machine sensing without investing in advanced manufacturing software, artificial intelligence, fog or cloud processing capacity, or without investing in big data and artificial intelligence.

Regardless of how generic they are and of how gradually they can be adopted, generic solutions offered by one-size-fits-all providers will not be efficient; these new technologies acquire economic relevance if they are customized to the specific characteristics of the industrial processes adopted by different companies. It is essential to make accurate diagnoses and forecasts of the capabilities and resources required to enhance the efficiency and effectiveness of the solutions a company intends to adopt. Pursuing process efficiency and product performance is a key competitive standard. However, this is the "easy step" and one that is predictable to some extent. Competitive sustainability requires companies to continually invest in innovations that are relevant to their business and doing this will change how they organize themselves and compete.

In this process, unique opportunities for strategic repositioning are created, always considering the created value/cost ratio of the innovations in question. The time has come to take action and anticipate changes that are to come with the aim of steering them toward competitive sustainability or mitigating possible negative impacts that may lead to the destruction of value.

1.3.2 General Warnings

Despite the existence of broad windows of opportunity for generating, absorbing, and disseminating innovations associated with each technology cluster, seizing these opportunities is neither simple nor risk-free. Ill-devised business strategies and public policies will be ineffective due to technological issues (for example, lack of synergistic measures contemplating complementary clusters) and to different types of constraints, including ethical and/or regulatory aspects that affect individual values; social and/or environmental aspects related to the production or use of technologies; techno-economic aspects associated with assets, technological and organizational capabilities, and complementary infrastructures; and normative and/or standards-related aspects associated with technical standards such as interoperability.

If companies are to meet the challenges posed by new technologies, they must address innovation at the highest decision-making and political level. This is necessary not only because of the current importance and increasing future importance of innovation for the economy, society, and culture. The ethical, regulatory, social, environmental, scientific, and technological implications arising from new technologies require attention at the highest-ranking decision-making bodies of the executive, legislative and judicial branches.

Brazil will face ethical, regulatory and normative challenges that remain unresolved, such as ensuring freedom of choice and the right to privacy, data confidentiality, and personal security. Also worthy of attention are the legal implications arising from the increasing autonomy of machines, such as liability and punishment for data access breaches and improper use, losses or accidents, and protection of industrial secrets. The regulatory framework for biotechnologies supported by omic technologies associated with the use and manipulation of genomes and stem cells will become increasingly complex. The normative constraints involved include particularly uncertainties regarding the definition of open source versus proprietary standards and the need for cryptographic protection for addressing ethical constraints.

Likewise, the implications for labor and qualification derived from these new technologies are very complex; throughout the world, analysts, entrepreneurs, and politicians are debating the relationships between new technologies and labor without knowing for sure what paths to follow so far. This is a debate that needs to be expanded in the country.

Brazilian citizens (as well as citizens from other countries) are still unaware of and have not perceived the above-mentioned implications. The direction is simple: the process of generating, using, and disseminating new technologies requires appreciation and expansion of Brazil's scientific and technological assets and capabilities. However, building them politically and economically is a complex task. This is a public and urgent matter to be addressed by the country's leaders.

2

THE DIGITIZATION OF BRAZILIAN INDUSTRY: WHERE ARE WE NOW AND WHERE ARE WE HEADED?

2.1 Digitization of companies: What to ask? How to ask it?

The diffusion of digital technologies in the economy, particularly in industry, has attracted worldwide attention from companies, research institutes, and governments. References to industry 4.0 as the “ideal target of desire” have become almost commonplace. However, this generic reference does not apply to countries with industrial structures diversified in terms of the range of existing activities and heterogeneous in terms of capabilities and performance. Moreover, it is functional neither for the debate nor to derive implications for productive and technological development policies.

Appropriate questions for contexts such as Brazil’s include: Which digital technologies are being used in the present and will be used in the near future? How to characterize “advanced” and “limited” digital companies? These are the topics investigated in this chapter. This analysis, therefore, affords an overview of the current and expected stage of digitization of Brazilian industry and serves as a gateway to the detailed and careful analysis of the impact of new technologies on different production systems and sectoral foci.

The information base is comprised of responses from executives representing a panel of 753[1] companies from various industries. An Internet survey managed by the CNI survey team[2] was carried out in the second half of 2017. The survey questions were based on similar studies carried out at UFRJ as well as on specialized literature and mainly on the Industry 4.0 survey conducted by CNI in 2016 (all cited in the References section of this chapter).

The majority of these studies seek to determine which of the so-called “4.0” technologies are used by the companies surveyed and what their requirements are. The Brazilian case required following an alternative trajectory for three reasons. First, digital technologies are available and have been used by industrial companies across all sectors for at least 30 years. This entailed considering the possibility that companies are using digital technologies of different generations. Second, regardless of the generation, digital technologies have been used in various business functions. Third, in Brazil there are significant differences in terms of capabilities and performance among companies, including in the same industry. Therefore, the field survey of Project I2027 sought to understand how companies are using different generations of digital technologies in different functions, based on international best practices. The survey questions were

1 For this summary, an econometric exercise (described in item 2.5) was conducted to test the consistency of the results and explore the relationships among variables. This exercise pointed out the need to exclude six companies from the panel, which led to the reduction of the sample from 759 to 753 companies. Thus, the results reported herein differ from those reported in the project’s Sectoral Technical Notes and Field Survey Report. The differences, however, are only marginal and do not affect the essence and the meaning of the results.
2 This team is very experienced; it conducts or commissions and analyzes all CNI economic surveys and had already carried out a survey on the topic in 2016. The field surveyof the I2027 project would not have been possible without the team’s high-quality and dedicated support.

developed with the assistance of digital technology experts, to ensure that they would be answered by all industrial companies regardless of the nature of their business[3].

The answers were provided by people in executive positions and with full knowledge of the activities of the company's best production unit (in the case of a multi-plant company). Obviously, answers about the future express the views of informed respondents. Therefore, they are not predictions but rather the respondents' expectations for the future. In this case, the exercise assumes that company executives are the most knowledgeable people to answer prospective questions.

2.2 The survey and the panel of companies

Following a critical analysis of the database to identify inconsistencies and lack of information, the original base of 813 respondents was reduced to 753 companies. Graph 6 shows the distribution of companies by size, production system, and capabilities.

Graph 6 – Characterization of the panel of respondents

Size(i)	Number	Proportion (%)
Large (more than 500 employees)	236	31.3
Medium-Large (250-500 employees)	223	29.6
Medium (100-250 employees)	294	39.0
Grand Total	**753**	**100.0%**
Production System	**Number**	**Proportion (%)**
Agroindustries	110	14.6
Capital Goods	135	17.9
Consumer Goods	148	19.7
Automotive Complex	48	6.4
Basic Inputs	110	14.6
Information and Communication	57	7.6
Chemical	112	14.9
Others	33	4.4
Grand Total	**753**	**100.0%**
Capabilities(iii)	**Number**	**Proportion (%)**
Low	228	30.2
Medium	218	29.0
High	307	40.8
Grand Total	**753**	**100.0%**

Source: Prepared by the I2027 project team.

3 In particular, the I2027 project team thanks Professor Eduardo de Sensi Zancul from the Production EngineeringDepartment of the Polytechnic School of USP, for his collaboration in this task.

To address the wide range of uses of digital technologies in different functions and the possible coexistence of different technology generations within a company, the survey started from two specifications: business functions and digital generation technologies. Five functions in which digital technologies are present were defined for the first specification: supplier relations, product development, production management, customer relations, and business management. For the second specification - since digital technologies have been and will be present in the daily lives of companies - four digital generations were defined with the following general specifications: **first generation - rigid production**: use of digital technologies for a specific purpose (CAD); **second generation - lean production**: flexible or semi-flexible automation using digital technologies without integration or with partial integration between areas (CAD-CAM); **third generation - integrated production**: use of digital technologies with integration and connection in all business functions (web-based sales support system); and **fourth generation - integrated, connected, and smart production**: use of digital technologies with information feedback in the operation and to support decision-making processes (business management with the support big data and artificial intelligence support). Figure 3 provides details of the characterization of the four generations of digital technologies.

Figure 3 – Functions and Generations of Digital Technologies

	SUPPLIER RELATIONS	PRODUCT DEVELOPMENT	PRODUCTION MANAGEMENT	CUSTOMER RELATIONS	BUSINESS MANAGEMENT
GENERATION 1	Manual transmission of orders	Computer-aided design system	Simple automation with unconnected machines	Manual drafting of contracts and records	Independent information systems specific by department/area, without integration
GENERATION 2	Electronic transmission of orders	Integrated design, manufacture, and engineering calculation system	Process partially or fully automated	Automation of sales activities	Systems formed by integrated modules and databases
GENERATION 3	Computer-aided purchase, stock and payment processes	Integrated product and process data management systems	Integrated process execution system	Web-based sales support system	Web platform with databases to support operation analyzes
GENERATION 4	Real time supplier relations	Product development through product and process virtual modeling systems	Automated production management through M2M (Machine-Machine) communication solutions	Customer relations through online monitoring of products in use. Monitoring and management of customers' lifecycle	Business Management with Big Data and Artificial Intelligence support

Source: Prepared by the I2027 project team.

In addition to specifying companies by size, production system and capabilities, two other characterizations were used based on the answers to the questionnaire about generations of digital technologies in use in 2017 and in the future and about the current attitude towards the generation expected for the future.

The first one characterizes the company according to its evolution in the use of digital technologies between 2017 and 2027[4]. Evolution was calculated for four business functions: supplier relations, product development, production management, and customer relations. As a result, companies are characterized by three types of adoption strategies.[5] For the **analog company**, the level of use of digital technologies (1G and 2G) in all functions is low today and will be low in the future; the **digital company** presents medium and high levels of current and future use of digital technologies (3G and 4G) in all functions, except the business management function; and the **selective company** presents medium and high levels of use of digital technologies in two ways, i.e., internal relations (product development and production management) or external relations (with suppliers and customers).

The second characterizes the company's attitude according to initiatives currently underway, in preparation for the generation of digital technologies that they intend to achieve by 2027. This information reveals the company's attitude towards its future, categorized into three types of attitudes: the **passive company** is that which has no projects or is conducting initial studies for all functions; **the plugged-in company** is that which has projects approved or underway in all functions, except the business management function; and the **focused company** is that which has projects approved or underway for functions associated with external or internal relations.

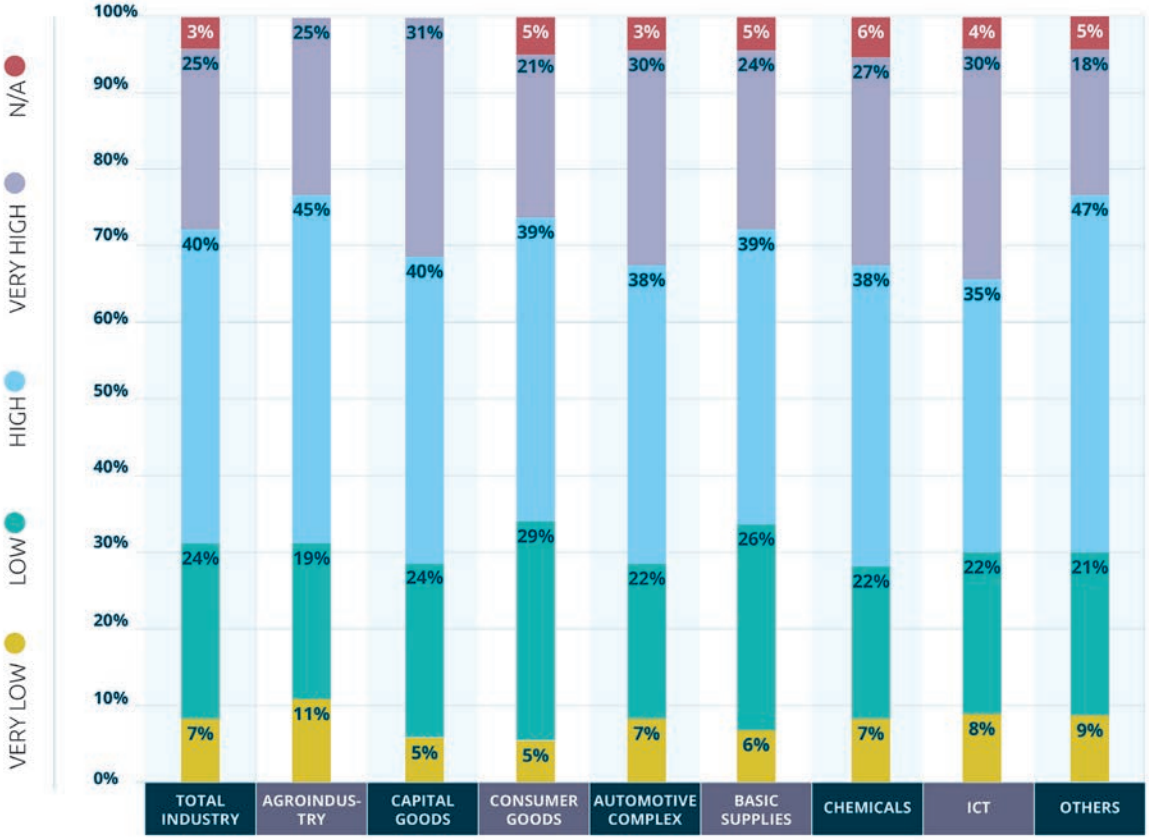
2.3 2027: Will advanced digital technologies become dominant in Brazilian industry?

What do business executives think about the future of Brazilian industry? Will there be a digitization process in the coming years? Will companies in all sectors undertake similar modernization efforts? What is the probability of 4G technologies becoming dominant in the company's business sector through 2027? The views of company executives were recorded according to four levels of probability: very high, high, low, and very low. The executives' sectoral expectations for all five functions are presented in Figure 4.

For most (65%) of the 753 executives, the probability of 4G technologies becoming dominant in their industries is high or very high. But there are some highlights. For 70% and 68% of executives in the Agroindustry and Automotive systems, respectively, the probability of 4G technologies becoming dominant in their industries in 2027 is high or very high. Executives in the Consumer Goods production system are slightly less optimistic. For 60% of them, the probability of advanced digital technologies becoming dominant is high or very high.

4 The movement intensity was obtained for each company by multiplying its position in 2017 (1, 2, 3, or 4) by the position in 2027 (also 1, 2, 3, or 4).
5 Because of its specificity, the most generic function (business management) was not considered.

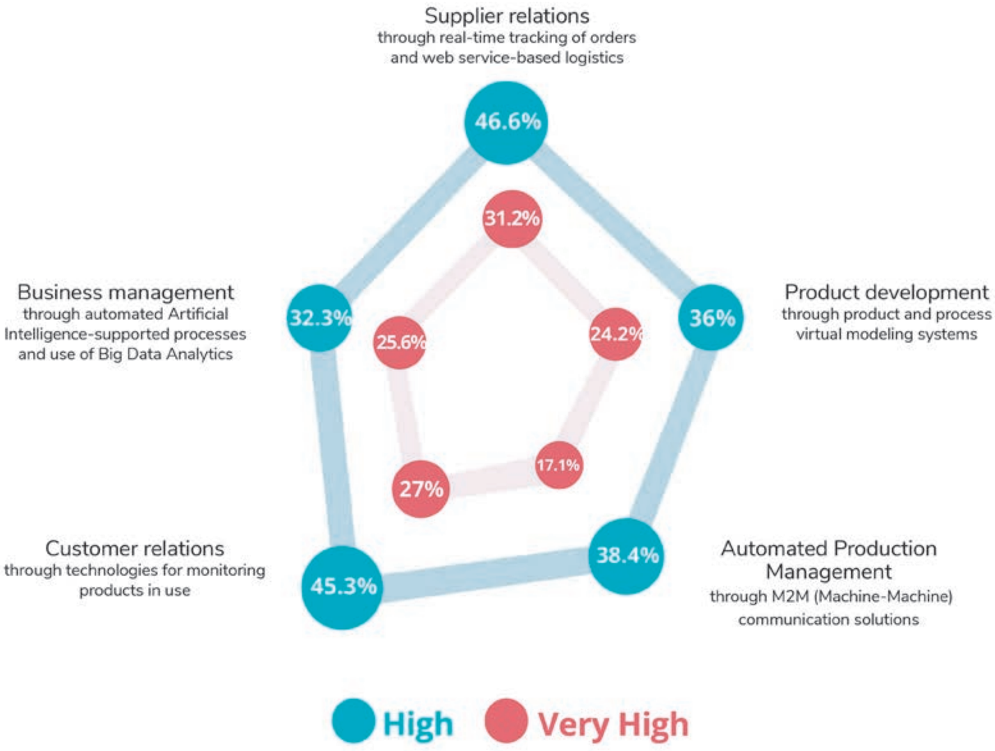
Figure 4 – Probability of 4G technologies becoming dominant in the company's business sector (in all functions) – Total for industry and production systems (in % of respondents)



Source: Prepared by the I2027 project team.

But in what business functions executives expect 4G technologies to become more or less dominant? As Figure 5 shows, the probability of 4G technologies becoming dominant in the future is higher for the company' external relations functions. Approximately 78% of executives indicated a "high" or "very high" probability for supplier relations and 72.3% for customer relations. On the other hand, in production management and business management, positive expectations were expressed by only 55.5% and 57.9% of executives respectively. This result is surprising because in order to be implemented, prominent business functions require coordination with other economic agents beyond the limits of the company itself, thus pointing to a more complex organizational challenge than that related to the company's internal context. Because of either the company's decision to seek greater interaction with customers and suppliers or the latter's pressure for closer relations, the fact is that the executives in this panel of companies recognize that the value chains of Brazilian industry will be more sophisticated and technologically updated in 2027.

Figure 5 – Probability of 4G technologies becoming dominant in the company's business sector, by function – Industry total (in % of respondents)



Source: Prepared by the I2027 project team.

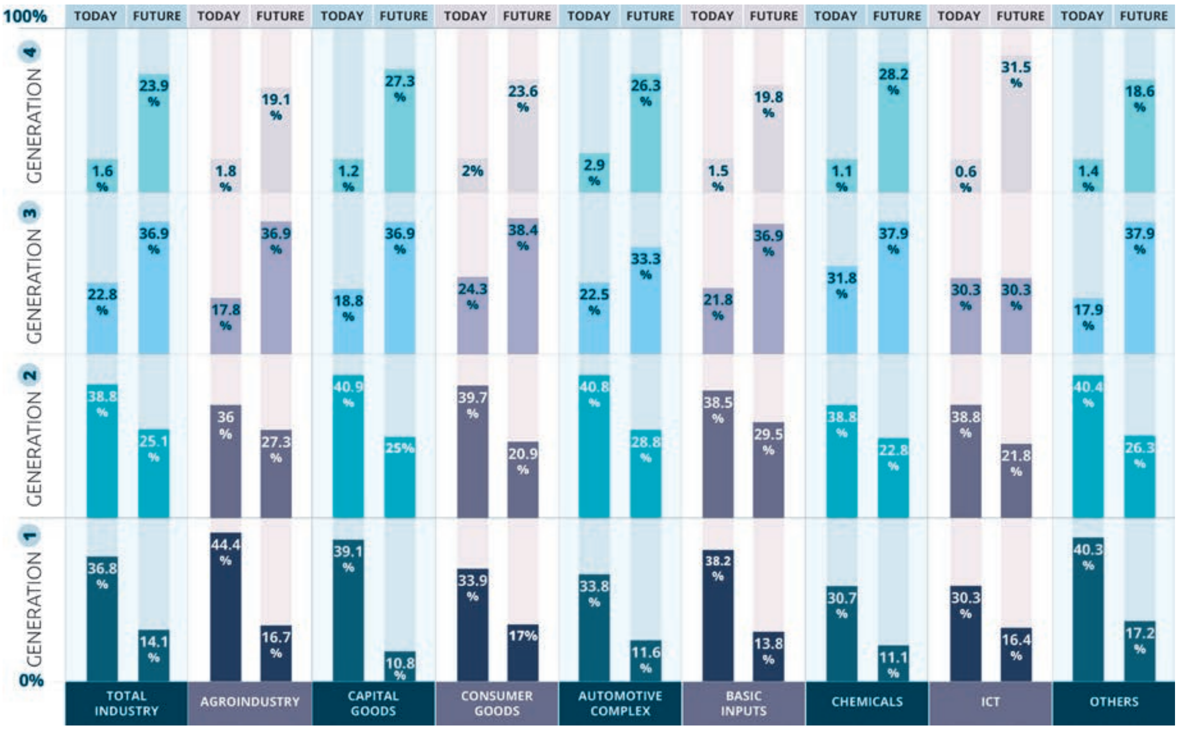
In summary, there is great convergence in the expectations of company executives for a process to accelerate the diffusion of advanced technologies in Brazilian industry over the next ten years. If these expectations are met, industry transformations will be important: companies will be more efficient and productive and able to provide updated goods and services adapted to consumer demands; value chains will be characterized by high technological intensity; companies will be competing for markets in competitive environments in which their competitors also have a high technological level. This is the scenario from which executives reflected on the current and expected use of digital technologies in their own companies.

2.4 2017 and 2017: Digitization in companies

While future expectations for the companies' business sectors are positive, the scenario changes when the current situation and the projections of Brazilian executives for their companies are factored in. Figure 6 shows generations of digital technologies in 2017 and expectations for 2027 for industry as a whole and for production systems.

In 2017, 75.6% of companies were in the first and second generation, 22.8% in the third generation and only 1.6% in the most advanced generation. However, there is a willingness to move forward, since 23.9% of them expect to be in the 4G league within the next ten years. The results by sector do not differ much from the industry average. Companies that were in the most advanced generation in 2017 were also in the most technology-intensive sectors: Chemicals, with 32.9% and ICT, with 30.9% of companies in the third or fourth generation.

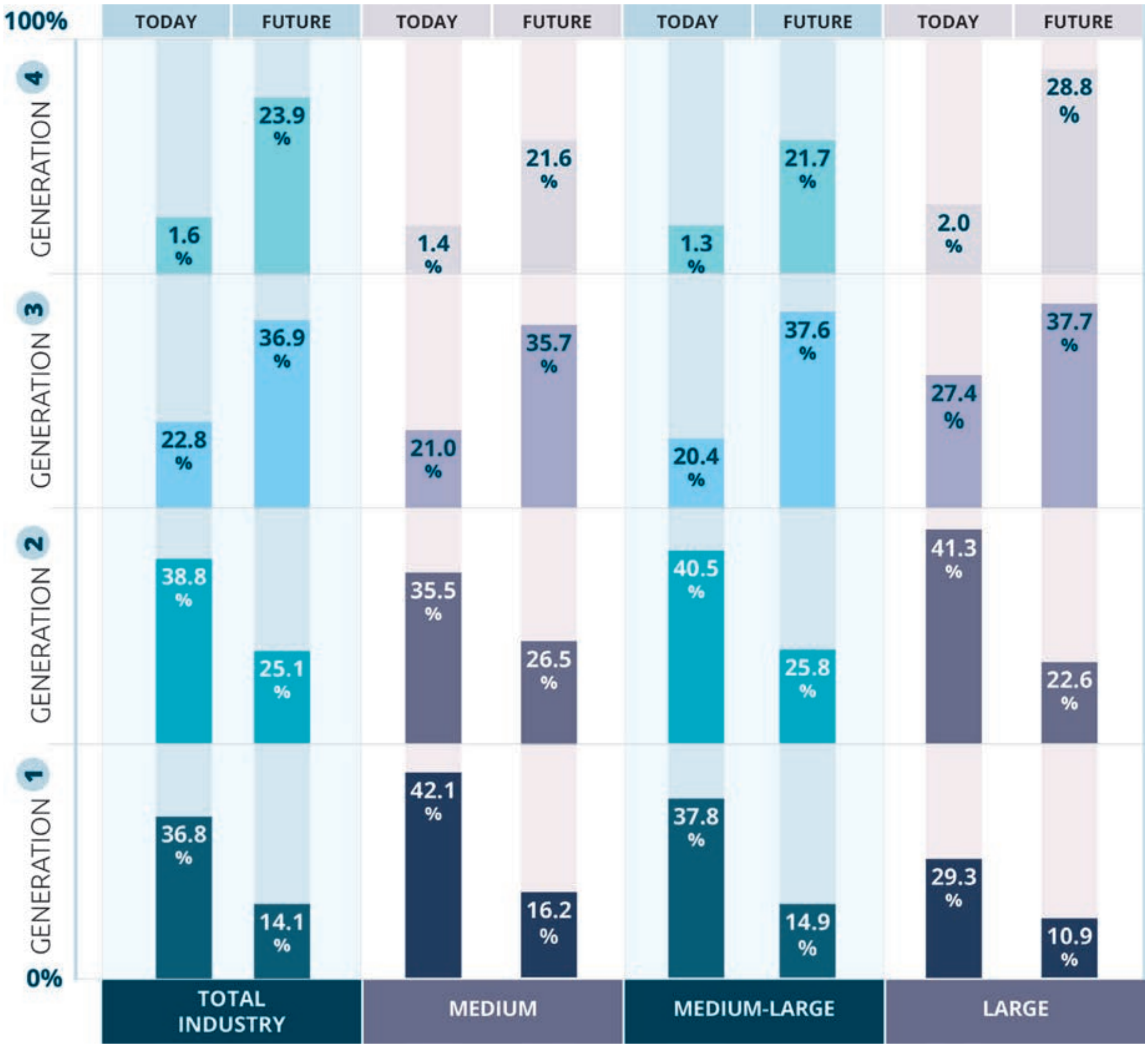
Figure 6 – Use of generations of digital technologies in 2017 and expected use for 2027 - Industry total and production systems (in % of respondents)



Source: Prepared by the I2027 project team.

The distribution of companies in terms of size and technology use in both 2017 and 2027 is convergent, with a slight difference in favor of larger companies: in 2017, first- and second-generation technologies were used by 77.6% of medium-sized companies, 78.3% of medium-large companies and 70.6% of large companies. However, when looking at future expectations, third- and fourth- generation technologies prevail for 57.3% of medium-sized companies, 59.3% of medium-large companies, and 66.5% of large companies. Almost one-third of this group expects to move up to the most advanced generation (Figure 7).

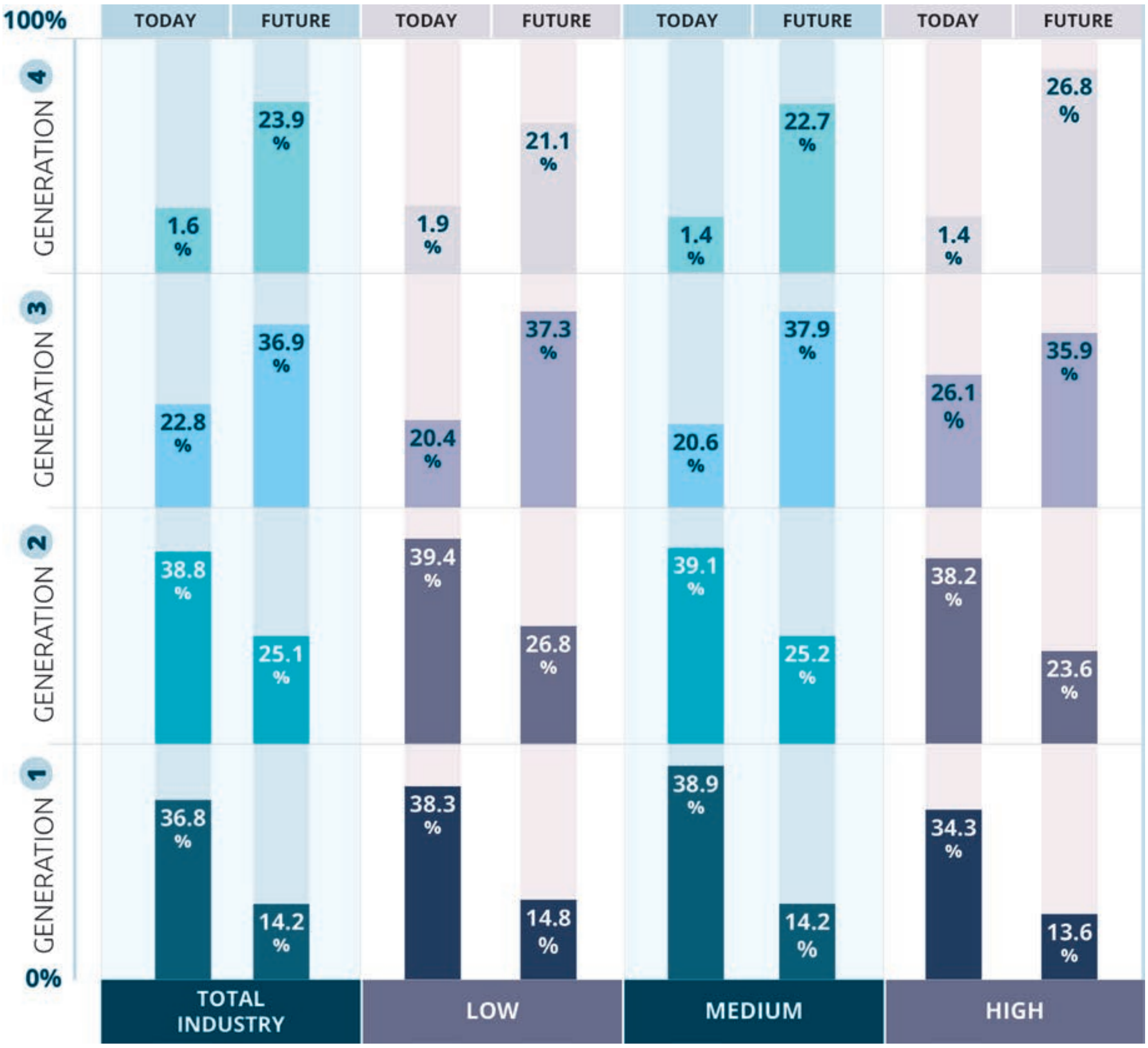
Figure 7 – Use of generations of digital technologies in 2017 and expected use for 2027, by company size (in % of respondents)



Source: Prepared by the I2027 project team.

This response pattern changes when considering the company's capabilities. In 2017, organizations with a higher proportion of professionals with degrees in science, technology, engineering, and mathematics in relation to the total number of employees made greater use of third- and fourth-generation technologies (27.5%). In the future, this proportion is expected to increase to 62,7%, as opposed to low-qualified companies (22.3% in 2017 and 58.4% in the future).

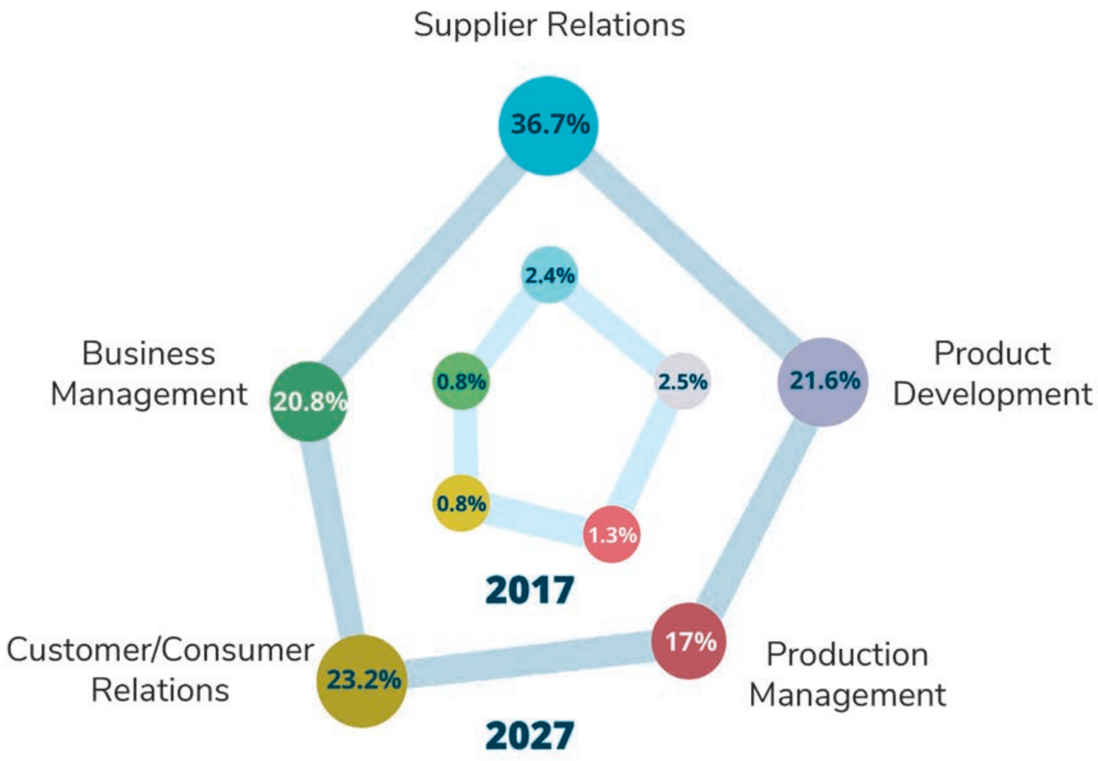
Figure 8 – Use of generations of digital technologies in 2017 and expected use for 2027 according to the company's capabilities (in % of respondents)



Source: Prepared by the I2027 project team.

The distribution of present and future uses of technologies according to the five organizational functions corroborates the results previously found for the probability of 4G technologies becoming dominant in the companies' business sectors. Figure 9 shows that expected advances in the use of 4G technologies between 2017 and 2027 are more pronounced in functions involving external relations.

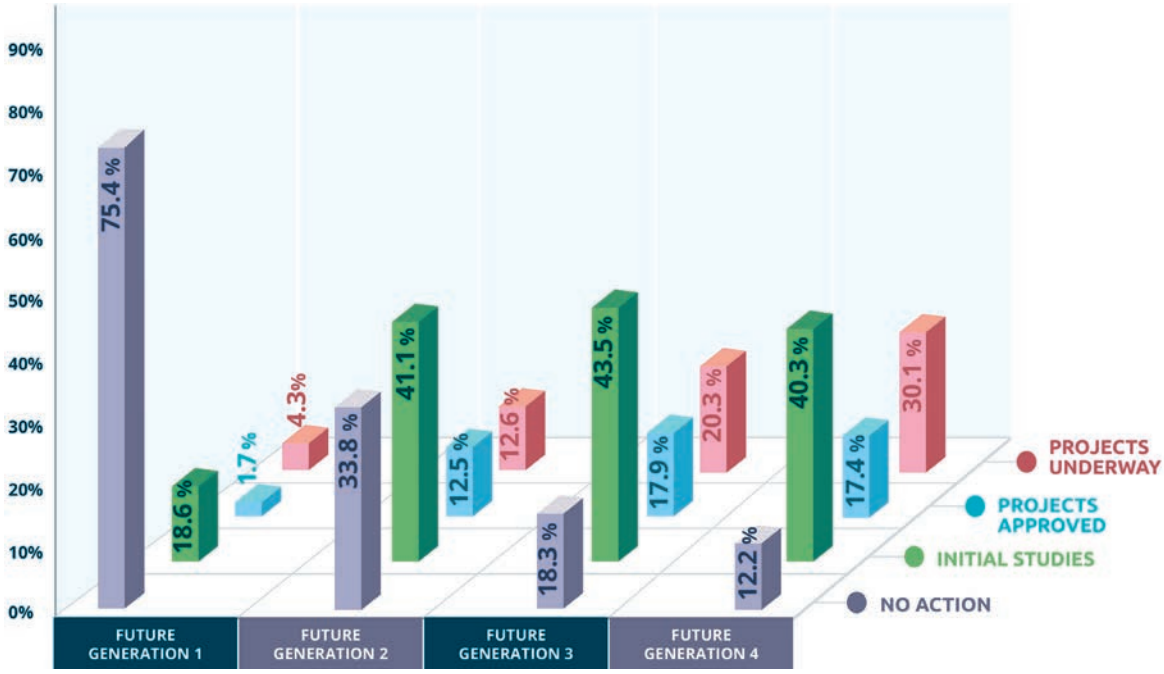
Figure 9 – Use of 4G technologies by companies in 2017 and expected use for 2027, according to the five organizational functions (in % of respondents)



Source: Prepared by the I2027 project team.

Executives also expressed their views on the type of activity implemented by companies in 2017, in preparation for the digital technology generation they intend to achieve in 2027. The possible responses were: no action at all; initial studies; projects approved but not started; and projects already underway. Figure 10 below compares these attitudes with the technology generation expected for the future.

Figure 10 – Digital technology generation in the future *vs.* actions underway for achieving it (in % of respondents)



Source: Prepared by the I2027 project team.

Of the total number of companies that expect to be in the fourth generation in the future, 47.5% already had projects approved or underway in 2017. On the other hand, more than 75% of companies that expect few advances for the future show a high degree of inertia. That is, the greater the expectation of using more advanced technologies, the higher the company's level of preparation to reach this desired future. On the other hand, the level of preparation is lower for companies that do not foresee significant progress in digitization.

2.5 How do companies differ from one another in their digitization movements?

The descriptive analysis shows largely consensual results: low levels of use of advanced digital technologies in 2017 and expectations for significant advances by 2027. However, there is growing dissent when the reference is the future. Is this dissent real or apparent? How to explore information about different evolution strategies in current and future uses of advanced technologies? Moving in this direction required resorting to quantitative techniques that enabled relating the use of digital technologies to the structural and behavioral characteristics of companies.

Based on the nature of the questions (categorical variables) and on the technical arsenal available (econometric regressions), the ordered logistic regression technique (Box 1) was found to be the most appropriate analysis instrument. Its use enabled exploring the extent to which differences in digitization movement strategies can be explained by variables that express structural and behavioral characteristics. These variables are:

- **Production system**: Would the likelihood to move towards digitization also be higher for more technology-intensive industries and lower for less technology-intensive ones?
- **Size**: Would companies with more or less resources also be more or less willing to invest in digital technologies?
- **Capabilities**: Would there be a direct relationship between capabilities and investment in digital technologies?
- **Attitude**: Would better prepared (plugged-in) companies be more likely to invest in modernization compared to less prepared (passive or focused) companies?

Box 1 – Ordered logistic regression

As the field survey variables are categorical rather than continuous, an ordered logistic regression was used in the econometric exercise. A logistic regression enables measuring the relationship between dependent variables and explanatory variables by estimating probabilities based on a logistic function. The result is the calculation of the probability of occurrence of a specific event related to a target category of the response variable to be understood. The option for ordered regression also considered the fact that the category ordering of the dependent variable of choice cannot be neglected[1]. This ordering is essential, since the answers that indicate current and future use of more advanced technologies are considered better than those that indicate stages that are still initial in the movement between generations of digital technologies. The basic equation of the generalized model[2] for M categories is:

$$P(Y_i > j) = \frac{\exp(\alpha_j + X_i\beta_j)}{1+[\exp(\alpha_j + X_i\beta_j)]}, j = 1,2,\ldots, M-1, \text{ where}$$

Y_i is the response variable and represents the variable to be explained;

X_i represents each explanatory variable;

α_j is the model's intercept;

β_j are the coefficients associated to the explanatory variables for M categories and express the effects of the variables.

(1) Long, J. S.; Freese, J. (2006) Regression Models for Categorical and Limited Dependent Variables Using Stata, Second Edition. College Station, Texas: Stata Press. Long, J. S.; Freese, J. (2014). Regression models for categorical dependent variables using Stata (3rd ed.). College Station, TX: Stata Press.

(2) Ordered logistic regression may consider the hypothesis of proportional (parallel regressions for each explanatory variable) or non-proportional odds of occurrence. The generalized model is that which considers both possibilities.

Source: Prepared by the I2027 project team.

Ordered logistic regression enabled determining the higher or lower likelihood of companies moving towards more advanced digital technologies between 2017 and 2027, depending on the company's behavioral and structural characteristics.

Figure 11 below links the probabilities of occurrence of three different strategies of movement towards digitization (analog, digital, selective) to three types or profiles of combinations of the companies' structural and behavioral characteristics: (i) medium-sized companies, with a low level of capabilities and no projects or plans focused on the technologies expected for the future (passive company); (ii) medium-large companies, with an intermediate level of capabilities and plans underway for external relations or internal functions (selective company); and (iii) large companies with a high level of capabilities and plans underway in both external relations and internal functions (plugged-in company).

Figure 11 – Probability of companies following a specific digitization strategy based on behavioral and structural determinants

DIGITIZATION STRATEGIES	SMALLER COMPANIES, LOW LEVEL OF CAPABILITIES, NO PLANS OR JUST CONDUCTING STUDIES	MEDIUM COMPANIES, INTERMEDIATE LEVEL OF CAPABILITIES, WITH PLANS APPROVED OR UNDERWAY IN JUST ONE OF THE DIMENSIONS	LARGER COMPANIES, HIGH LEVEL OF CAPABILITIES, WITH PLANS APPROVED OR UNDERWAY	% SHARE OF PRODUCTIVE ECOSYSTEMS IN EACH DIGITIZATION STRATEGY (TOP 3 SYSTEMS) OR PROBABILITY OF THE DIGITIZATION STRATEGY OCCURRING IN THE DIFFERENT PRODUCTIVE ECOSYSTEMS (TOP 3 %)
ANALOG	75.07%	34.59%	8.43%	1st ECOINDUSTRIES (63,3%) 2nd OTHERS (56,7%) 3rd BASIC INPUTS (50,7%)
SELECTIVE	19.36%	39.83%	25.39%	1st ICT (34,4%) 2nd CHEMICALS (33,1%) 3rd CONSUMER GOODS (33,1%)
DIGITAL	5.57%	25.58%	66.18%	1st ICT (25,7%) 2nd CHEMICALS (22,4%) 3rd CONSUMER GOODS (22,4%)
TOTAL	100.00%	100.00%	100.00%	

Source: Prepared by the I2027 project team.

The results presented in Graph 1 indicate that structural characteristics (size and sector) and the two behavioral characteristics (attitude and capabilities) act as determinants of different movements towards the digitization of companies:

- **Digital companies**: The probability of a company adopting an advanced digital strategy is 66% for larger companies with a high proportion of highly qualified staff and projects approved or underway. This strategy is more likely to occur in the ICT, Consumer Goods, and Chemicals production systems.
- **Selective companies**: A selective strategy is more likely to be adopted (almost 40%) by medium-large companies with an intermediate level of capabilities and projects approved or underway in a given dimension (internal or external). This strategy is more likely to occur in the ICT, Chemicals, and Consumer Goods sectors.

- **Analog companies**: There is a 75% probability of a limited digitization strategy occurring in smaller, lower-qualified companies, with no projects for their future digitization. The production systems in which this strategy tends to stand out are Agroindustry (63.3% probability of the company being analog), Others (gathering companies from other sectors), and activities related to Basic Inputs, in which the probability of the company being analog exceeds 50%.

2.6 Requirements for a sustainable digitization trajectory

The executives of Brazilian companies expect Brazil's industry to follow an expressive modernization trajectory through digital technologies. For most of them, the probability of advanced digital technologies prevailing in their business sectors is high or very high. This means a competitive environment marked by technological sophistication, particularly in the company's relations with its suppliers and customers. According with the expectations of industry executives, advanced digitization will mark Brazil's competitive environment in 2027.

If this is the competitive environment expected for 2027, the relative position of each company in 2017 can be characterized as being at least challenging. The levels of use of advanced digital generation technologies were very low in 2017, in all business functions and by companies in different sectors, sizes, and capabilities.

However, when the reference is the future, expectations for the digital modernization of companies are very positive, even where the level of consensus is not so high in relation to the use of technologies in 2017. Because of a greater dispersion of responses in the field survey, consistency tests of the digital modernization strategies of companies were conducted to determine whether these are explained by structural or behavioral characteristics.

The results show that the probability of companies evolving towards advanced generations of digital technologies is higher (i) if they adopt proactive attitudes in the form of future plans approved or underway; (ii) if they have capabilities in the form of skilled staff; (iii) if they are larger; and (iv) if they originate in somewhat technology-intensive sectors. The implications of these factors are very relevant.

Based on structural characteristics, are large companies from specific industries the ones with the highest probability of moving on to the digital world? Certainly, larger companies can mobilize the resources (financial and others) required for investing in digitization with relatively greater ease. Similarly, companies from sectors with a technical base that already incorporates the digital paradigm will also move more easily towards modernization. However, companies of other sizes and sectors can also move forward. In particular, modernization strategies focused on specific functions such as external relations with the aim to strengthen ties with suppliers or customers, or on internal relations with the aim to develop products or manage digital technology-intensive processes are suitable for companies in sectors other than high-intensity ones or for smaller companies.

In addition to structural characteristics, the behavioral characteristics of companies are equally or more relevant for advancing in digitization: investments in capacity-building and the development and implementation of digital modernization strategies in the long term. Investment and attitudes to strengthen digitization processes are independent of size or sector of origin and are decided by their leaders. The future of companies depends on the willingness to invest in capabilities and develop strategies for the use of digital technologies.

Companies with modernization projects approved and underway are more likely to use more advanced digital technologies in the future. Companies that were doing nothing in 2017 to prepare themselves are also those that are moving towards less advanced generations of digital technologies and vice-versa. The message of Brazilian executives could not be clearer: the future is built through investments in capacity-building, based on long-term plans implemented on a daily basis.

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3

INNOVATION PRODUCER SYSTEMS: KEEPING UP WITH THE PRODUCTION FRONTIER AND EXPLORING SYNERGIES WITH COMPETITIVE SECTORS

3.1 What are the innovation producer systems?

Innovation producer systems comprise the production of Information and Communication Technology (ICT) and Capital Goods (BK) equipment and systems. For the I2027 project, the former includes products that enable the dissemination of digital technology innovations for itself and for other industries: microelectronic components, software and telecommunications equipment and systems, as well as access devices (PCs and smartphones), displays, and high-performance computers. The delimitation of the capital goods industry is restricted to the machinery and equipment sector: agricultural machinery and equipment, machine tools, energy generation, transmission and distribution equipment, and serial electrical goods for industrial use.

The differences between these two production systems are very clear: ICT has a technical base of electronic origin, whereas BK is of mechanical origin; mechanical capital goods emerged in the nineteenth century; the transistor, which gave rise to the ICT key-technology (the microprocessor) emerged during the 1940s; the role of ICTs is to process more information in an increasingly smaller physical space; the role of BK is to process a growing number of operations with increasing accuracy for a variety of economic activities, to which product diversification is essential. Of great importance is the fact that progress in the BK system is increasingly dependent on the incorporation of digital technologies for the equipment command function.

Why, then, bring them together? Because they share four attributes of a technological and competitive nature and a particularity, in the Brazilian case, in terms of innovation capabilities and competitive capacity. The common technological attributes are: (i) like specialized producers (see Chapter 5), these are knowledge-intensive activities that depend on the results of the scientific and technological efforts of companies and of the innovation ecosystem with which they are associated; (ii) the rate of technological change is very fast; (iii) the capacity to differentiate products and services largely defines competitive success; and (iv) unlike specialized producers, the innovations developed or absorbed and applied here are generic application technologies.

Also different from specialized producers are the particularities of these production systems and sectoral foci in the Brazilian case: much of the local production comes from companies with limited capacity and competitive performance (whether revealed or potential); imports play a relevant role in meeting the demand for electronic or mechanical equipment; and in specific market niches, Brazilian companies have the potential capacity to keep up with the international technological frontier.

3.2 What is the economic importance of innovation producer systems and what are the determinants of technological change?

To a large extent, the main determinant of change in ICT and BK stems from advances in digital technologies along the following trajectories: (i) increasing information processing capacity in ever smaller physical spaces; (ii) increasing ease of use and intelligence incorporated into technological solutions; and (iii) increasing supply of goods and services at decreasing costs (e.g., Moore's Law in microprocessors).

The importance of the ICT system can be assessed by its economic weight, which accounts for 5% of global GDP and around 9% of the economic value added in global industry. The 2016 global revenue was estimated at US$3.8 trillion. In that year, the United States represented the main ICT market, with 31% of the total. But Asia, which is growing rapidly and accounted for 29%, should take the lead in the short term. Europe accounted for 24%, Latin America for 9%, and Africa for 7%.

The true importance of the ICT system is associated with the capacity revealed in the last decades to develop solutions that radically change the products and production processes of a wide range of economic activities, mainly in industry. As seen, several of the clusters that generate long-range disruptive innovations are associated with digital technologies.

Over the next ten years, the market for solutions or platforms to develop businesses through ICTs is expected to grow in density, diversity and scale, as the Internet of Things (IoT) expands and smart and connected manufacturing systems spread. The ICT industry is directly affected by these transformations, because it is at the same time a pioneer in the use of emerging technologies and a generating center of critical innovations for the rest of the economy.

In Brazil, the turnover of the information technology market, including IT hardware, software, services, and exports reached US$39.6 billion in 2016, representing 2.1% of Brazilian GDP and 1.9% of total IT investments worldwide. Of this amount, US$8.475 billion came from the software market and US$10.227 billion from the services market.

The growth of the ICT system in Brazil has been underpinned by the software and services segment, while hardware production has been falling since 2013. Brazil is not a relevant global player in the manufacture of electronic components and equipment. Products with a high imported content are locally assembled by Brazilian manufacturers for the domestic market. Brazil ranks 11th in the IT software and services market and fourth in number of servers connected to the Internet. Data from 2016 show that 22.5% of the Brazilian software market corresponds to products developed in the country. In 2016, the use of locally-developed computer software (including custom software) accounted for 31% of the total investment in information technology. More than 15,000 companies are dedicated to developing, producing and distributing software and providing services. Of this total, nearly 5,000 are software developers. Some Brazilian management and service software companies are of recognized competence, including in the international competitive scenario. An upward trajectory is the emergence of digital-based startups, especially to serve specific sectors such as the financial industry (fintech) and agriculture (agritech).

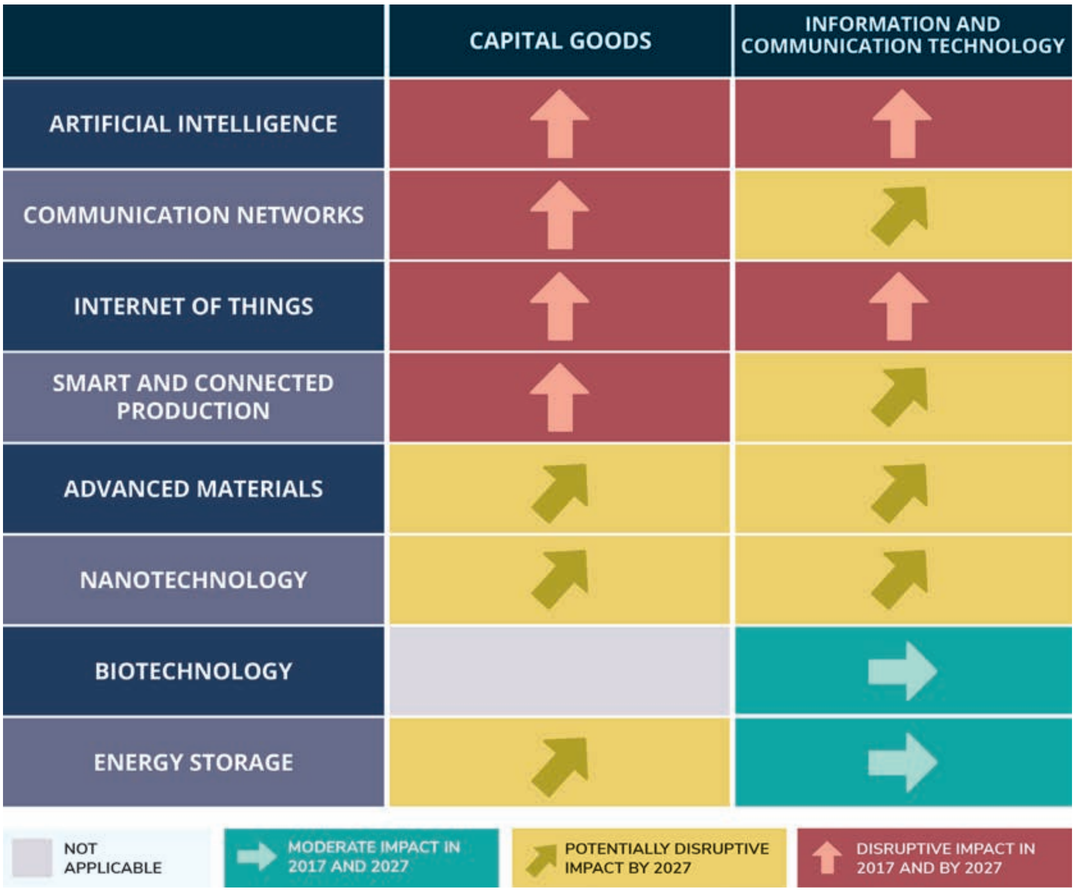
The BK production system, which accounts for approximately 12% of the total value of global industrial production, is also an important center of generation and diffusion of innovations to the industry. Geographically, production has kept up with the shift of industrial activity to the Asia-Pacific region, especially China, which accounted for 42.7% of world production in 2016.

Brazil has a sophisticated capital goods production system, led by subsidiaries of transnational companies in virtually all segments. It also has a group of skilled domestic companies that have internationalized their production. The combination of foreign subsidiaries with domestic companies ensures a diversified and up-to-date supply of equipment. Investments in economic activities such as agriculture, mining, oil extraction, energy generation, and manufacture boost the production of capital goods and attract investment. Brazil ranks 11th in the production and consumption of capital goods worldwide. Brazilian production accounts for a little over 1% of the global total and is destined for the domestic market. Exports represent 19% of production while imports represent 33% of sales in the Brazilian market.

3.3 What are the relevant technologies and their potential impacts?

Graph 7 below shows the relevant technologies for ICT and BK. The ICT industry is responsible for the development - and at the same time is a pioneer in the use - of emerging technologies such as AI. Based on families of mathematical and statistical algorithms, AI covers different areas, which are defined according to the informational resources and inputs used. Cloud computing has enabled storing big data and given rise to new information access services, including applications, search engines, communication networks, and data storage and processing centers. The development and manufacture of equipment changes substantially with the introduction of cyber-physical systems for the interconnection, digitization, processing, and optimization of equipment-embedded information. At the same time, digital solutions are seen in production processes (smart and connected production), increasing the flexibility of plants, which in turn enhances the product diversification potential of companies. Innovations in advanced materials, nanotechnology, and energy storage will drastically change the status quo of capital goods production in the next decade.

Graph 7 – Relevant technology clusters: Capital Goods and ICT



Source: Prepared by the I2027 project team.

3.3.1 ICT

At the international level, a process of potentially disruptive digital innovations has been triggered by the convergence and integration of solutions that were being developed for several decades in parallel, but that currently have strong synergies to jointly bring about radical innovations.

Rapid advances on the Internet driven by IoT and SCP have enabled technologies like big data and data analytics, machine learning, AI, robots and systems with cognitive abilities, virtual reality, high-performance processors, and advanced communication networks to be developed and applied in the reformulation of the business models and coordination practices of economic agents.

Technology platforms that integrate software, systems, and equipment are becoming the foundation for making digital products and services available to companies and individuals. These platforms are organized in layers - their technical bases rely on equipment and processing systems integrated through the Internet which, in turn, support layers of services and applications that can be grouped for different types of uses, vertical markets and applications, content producers, etc. Competing in just one stage or layer without being included in integrated platforms can pose a high risk to independent companies.

Over the next ten years, the market for digital solutions or platforms is expected to grow in density, diversity and scale, as IoT expands and smart and connected manufacturing systems spread. The ICT industry is directly affected by these transformations, because it is both a generator and a user of solutions. The main expected impacts of IoT and advanced manufacturing in the ICT system are upstream the value chain, especially in microcontrollers, sensors and actuators; microchips for embedded use; and distributed processing capacity (cloud and fog). There will be a great need for smaller sensors with low energy consumption and compatible costs.

Suppliers of integrated circuits already offer IoT solutions with different degrees of customization and meeting a more specific set of requirements of the "object" to be interconnected. In an estimated five to ten-year timeframe, complete, customizable IoT solutions will be available for various market segments. These component solutions are, for example, systems-on-chips (SoC) containing communication modules (usually wireless) and embedded sensors; open-source processors; customized SoC and safety and privacy devices and software. A similar process is also underway for the advancement of integrated smart manufacturing systems. Integration companies develop customized solutions to sense, connect and optimize parts or the set of the production processes of companies interested in moving towards smart and connected production. Companies in the machinery and equipment sector are developing complete "mechatronic" solutions either alone or in partnership with companies engaged in production automation and advanced management.

In the fields of big data, cloud computing and AI, the transformative impacts on the ICT production system should be gradual. The diffusion of data analytics and AI depends on the integration of systems in organizations, a condition still unavailable to most potential users. Legacy systems that are not compatible with each other, both within companies and especially in the production chain, are a barrier to AI that will be hard to overcome in the short term. Nevertheless, as the adoption of new digital technologies advances, their impact on productivity and business models will be immediate and significant.

An exception is the software industry. Because of its very nature, advances in this industry products require the incorporation of growing connection, integration, and intelligence. And to offer solutions such as these, software companies change their business models so as to offer information storage and processing in the cloud as well as big data through customer sensing. The expansion of open source architectures is a strong trend, as are business models of the product-as-a-service and product sharing types. Therefore, servitization, that is, the offer of solutions and services according to the specific requirements of customers becomes the guideline for the business models of companies formerly known as “software companies”. The prices of their services are currently 30% lower than four years ago and are expected to fall another 30% in the next three to four years, causing companies that fail to upgrade technologies and business models to go bankrupt. At the same time, we have the emergence of knowledge-intensive business services (KIBS) which, due to their origin and size, develop “focus” solutions suitable for specific customers. Because they are smaller companies, they have greater flexibility to adjust to market changes and serve customers quickly as compared to larger companies.

It should be pointed out that the development of new applications and AI customization for different users require highly skilled human resources, which are scarce both in Brazil and abroad. The rate of AI diffusion also depends on the availability of high-speed communication networks and on computational capacity to process and make large volumes of data available. AI is spreading more rapidly in advanced marketing service segments, such as the crossing of multiples of consumption patterns, political and social preferences, and location of users and consumers.

Technological changes have been affecting the telecommunications sector by accelerating convergence to network platforms based entirely on IP and packet switching. Migration to fully digital networks will result in significant efficiency gains; data centers will become more important in network infrastructure, making room for capacity growth and transformations in traffic patterns, thus boosting cloud computing applications.

Coupled with the expansion of IP-based networks, software-defined networks (SDN) are expected to become a pattern. This architecture, which enables shifting network control from the edge (routers and switches) to the center of the network (servers) matches the interests of cloud computing providers and allows for greater flexibility and real-time response to changes in demand and traffic. However, it can be disruptive to equipment and systems manufacturers if they fail to adapt to pattern changes. A technology pattern for network virtualization is yet to be achieved, but the network functions virtualization (NFV) technology is set to become a pattern and is already part of equipment design, including by Brazilian companies. The wide adoption of these two technologies (SDN and NFV) will be driven mainly by the need to reduce costs for telephony operators.

The transformative impacts of new network technologies on the ICT production system are associated with the creation of opportunities for hardware and specialized technical services segments. They also pose a threat to telecommunications and pay TV companies that maintain expensive services against web-based options. The increased use of private networks and proprietary technologies in networks can cause an increase in barriers to the entry of smaller companies. In Brazil, the low availability of infrastructure in much of the country could delay the widespread diffusion of advanced network services.

The virtualization and integration of industrial plants with their customers and suppliers should create a demand for customized components, thus opening up opportunities for the design and/or manufacture of products such as sensors, actuators and MEMS, SoC, smart production controllers, and middleware/gateways. The need for new embedded hardware and software will provide opportunities for the production of dedicated chips with smaller production scale and processing capacity (application-specific integrated circuits -ASIC).

3.3.2 Capital goods

The cluster of technologies comprising smart and connected production (AI, IoT, advanced communication networks, in addition to additive manufacturing technologies and robotics) as well as advanced materials, especially those that afford greater resistance and less weight, already have disruptive impacts on the Capital Goods production system. Signs of change can be seen in the competitive conditions for machinery and equipment production resulting from the evolution of advanced manufacturing technology. Market structures and business models in the production system are beginning to reflect the transformative impact of new technologies.

The introduction of cyber-physical systems of interconnection, digitization, processing, and optimization of product development and manufacture with increasing use of artificial intelligence is an important process innovation in economic activity and represents, for the manufacturers of Capital Goods, a new market of great potential. Machines are connected and accessible as objects in the network, and may have data in real time, which are subject to exploitation, analysis and intervention through the network itself. In addition, machines can store documents and information about themselves outside of their physical bodies, thus entailing virtual representation with own identifiers as well as machine learning ability. Smart and connected production should therefore make room for a new level of interaction between the physical and virtual worlds.

It also enables the emergence of new business models, product lifecycle optimization, reconfigurable manufacturing systems, and vertical integration of actuators and sensors up to enterprise resource planning (ERP) systems. Thus, value generation in the production chain occurs not only at the manufacturing stage, but mainly in the upstream and downstream stages of production. Upstream activities include R&D, supply chain, and process planning activities. Downstream activities include the distribution, maintenance, and monitoring of the product lifecycle.

For the manufacturers of capital goods, these are product innovations that will be intensive in terms of communication infrastructures, coupled with AI. This requires that companies have the capacity to integrate equipment technologies and industrial processes such as advanced robotics or additive manufacturing and associated technologies such as big data into the production chain in which these technologies are applied. Architectural advances thus become increasingly complex, uncertain and disruptive, since the best ways for companies to unite their various departments internally and integrate with their customers and suppliers will vary and be specific for each company.

The competencies required go beyond the scope of the technologies traditionally mastered by mechanical and electrical equipment manufacturers. They represent a significant leap in relation to the challenges posed by microelectronic automation in the 1980s, when the spotlight was on computer-aided design (CAD), computer-aided manufacturing (CAM), and computer-aided engineering (CAE), in addition to flexible manufacturing systems (FMS).

The demand for new competencies has led producers of capital goods to organize cooperation networks for the joint development of products, partner with companies from other sectors - notably from the ICT system - and try to capture new technological assets through mergers, acquisitions, or international investments. These initiatives aim to both seize new opportunities and defend the companies' current market positions. At the same time, opportunities are being created for the emergence of new players (startups) and the entry of new competitors.

Leading digital technology companies such as Google, Amazon, Microsoft, Apple, and IBM have enough competencies and resources to capture new markets. They are therefore potential partners and competitors of traditional manufacturers of mechanical and electrical capital goods. IBM, for example, has chosen agribusiness as a strategic area for its operation in some countries, including Brazil.

Currently, the introduction and the impacts of smart production tend to occur incrementally, focusing on specific stages of the production chain. There seems to be no business arrangements - in the sense of companies interconnected with suppliers and customers - using smart and connected production systems at the limit of the technique. There are very few cases of manufacturing facilities that use them to the fullest. There are, however, pilot initiatives demonstrating the feasibility of radically innovative organizational arrangements.

The increased number of smart production solutions in the coming years will entail significant changes in both user sectors and equipment manufacturers. This will be reflected in market structures and in competition strategies in the capital goods system. The convergent evolution of AI, IoT and networks should enhance the disruptive impact of SCP by 2027. Innovations in advanced materials, nanotechnology, and energy storage should also dramatically change the system's status quo over the next decade.

Connected and smart production, however, brings impacts at different speeds across different segments of the capital goods industry. In the **agricultural machinery** sector, a radical leap is expected to occur in production mechanization through the use of autonomous and connected vehicles (tractors, harvesters, seeders, etc.) and remote monitoring of soil and crop conditions, in addition to favoring integrated upstream and downstream value chain management; the tractor is a mandatory gateway to the point where digital technologies and biotechnology-based solutions converge towards precision agriculture. In the **machine tools** segment, an increase is expected in the precision and flexibility of multiple use equipment as well as in production virtualization capacity, including the design, manufacture and use of all types of machines, besides the incorporation of additive manufacture. In the segment of **energy generation, transmission and distribution (GTD) equipment**, the growing incorporation of sensors, the integration with (smart) energy networks and the development of solutions for renewable sources are expected to occur. In the segment of **electrical serial products for industrial use** we should see the increasing incorporation of connected actuators and sensors, more efficient energy consumption, and the development of new applications (electric motorization of vehicles).

3.4 Where are we now and where are we headed? Relevant technologies in companies

3.4.1 ICT

The global ICT goods production system has gone through intense transformation, specialization, outsourcing, and relocation processes of both production chains and R&D activities. Moreover, product, system, and equipment development cycles have followed fast, if not disruptive trajectories. In the meantime, the configuration of Brazil's industry, with very few exceptions, has lagged behind in terms of products and systems.

Hardware production, which is highly automated and intensive in sophisticated capital goods has become a very specialized and largely outsourced activity. Only companies operating at high scales with an eye on the global market and that enjoy a favorable institutional environment can subsist in a vertically integrated manner. Asian industry currently concentrates most of the world's production and is able to produce on a large scale and achieve economies of scope through big CEM (contract electronics manufacturer) or ODM (original design manufacturer) contracts in a wide range of electronic products manufactured in flexible, highly productive factories. Large US corporations typically outsource hardware production to focus on innovations in electronic design and basic software, holding intellectual property rights and the most lucrative layers of software and services associated with their platforms.

In Brazil, on the other hand, there is a decline in both the production and share of assembled hardware. Indeed, factors of a structural nature explain the problems faced by Brazilian industry: (i) a global decrease (in terms of value) in the relative share of hardware manufacturing activities, as opposed to the expansion of telecommunications services, new digital services, and respective software; (ii) a tendency for increased competition and concentration of component production and assembly of end hardware in Asia; (iii) few logistical and operational advantages for Brazil; and (iv) a shortage of innovations actually developed in the country.

In Brazil, opportunities for the ICT industry are associated with system and component design as well as with the development and implementation of management and application software for different economic activities. The manufacture of microelectronic devices could involve smaller scale products developed for specific applications.

In the semiconductor segment, manufacturing is also concentrated in Asia, and in the last decade there has been a significant increase in both capital intensity (especially in the wafers manufacturing and chip encapsulation industries) and R&D intensity in the sector. Because of the heterogeneity of the Brazilian context, design and manufacturing activities are facing great difficulties to survive.

The global industry of telecommunications equipment and systems, in turn, is undergoing a transformation process similar to that observed in the computer segment: transition to more software-intensive and service-intensive business models; reduction of barriers to entry; and reduction of profit margins due to increased competition between telephony operators and telecommunications services. In Brazil, the competitive capacity is low due to the high cost of imported components, low production scale and high operational and logistic costs. However, the potential domestic market, which has been supplied with increasing imports of ready-made products, becomes an opportunity for manufacturers established in the country.

Advances in IoT and SCP in Brazil will provide meaningful opportunities for the ICT industry. The main opportunity lies in the development of solutions based on software and/or on software embedded in integrated chip components or in integrated SoC components. The development of these solutions requires companies to have in-depth knowledge of their client's business, in order to transform it and make it more productive. The main spaces for IoT are upstream the value chain, especially in microcontrollers, sensors and actuators, microchips for embedded use and distributed processing capacity (cloud and fog). There will be a great need for small sensors with extremely low energy consumption and compatible costs. Brazilian suppliers of integrated circuits already offer IoT solutions with different degrees of customization and meeting a more specific set of requirements of the "thing" to be interconnected. Also, telephony operators in Brazil are expected to migrate to an IP-based system of fully digital networks. There will still be a market for domestic providers of hardware and maintenance and support services for legacy networks. However, these companies are faced with the possible migration of demand to software-based solutions over generic hardware.

Prospectively, hardware producers need to develop services and partner with other companies to understand the needs of IoT users, of advanced manufacturing and of other emerging technologies, thus benefiting from demands that require efforts in adapting to the size and characteristics of the local market. More than producing isolated components, the future of Brazilian ICT companies depends on their capacity to develop project designs with the aim to integrate different hardware, software and service components into customized systems or solutions.

Unlike what was found for hardware production, the software and services sector in the country is thriving. In recent years, the sector has reported positive growth rates, above the economy as a whole, and boasted significant innovation rates. Some Brazilian software and software service companies, such as TOTVS and Stefanini have gone international, operating mainly in Latin America but also seeking to enter the competitive European and North American markets. Startups located in technology parks and targeting specific market niches will have interesting chances, due to easier access to the pool of skilled labor and to other companies/clients. The challenge for this segment lies in both technological capabilities and management capacity.

The capacity to meet the demand of user companies for innovation and to design and integrate solutions combining local and imported components is a critical aspect of local industry capabilities. Incentives to contract the design and projects of systems and solutions in the country is a key condition for generating a production and technological chain. This is a demand-driven relationship based on existing and potential capacity and different from a posture in which equipment used to be designed and produced without due consideration to the specificities of demand. The executives interviewed by the I2027 project team foresee an intensive use of advanced digital technologies in all business functions (product development, production management and, in particular, customer and supplier relations). Expectations of intensive use of advanced technologies define an interesting market potential for providers of technological solutions. The path towards customized ICT products is a strong trend and an opportunity for Brazilian industry, similar to paths identified in the pharmaceutical, processed food products, consumer goods, and specialized equipment industries.

3.4.2 Capital Goods

The Capital Goods system closely follows the world's best production and management practices. The potential advantages of integrated, smart and connected production should therefore be widely exploited in these activities, thus generating demand for solutions of this type. On the supply side, the capital goods production system in Brazil benefits from the presence of global companies whose parent companies are active in the development of advanced solutions while nationally-owned companies follow best practices.

Leading companies, whether domestic or subsidiaries of foreign companies, have access to technical, business, and financial resources to meet market challenges, although not always in the same conditions as their competitors from other countries. This group of companies and their sophisticated customers recognize the disruptive potential of new technologies and mobilize their resources based on this recognition. However, despite recognizing the importance of the changes underway, relatively few small companies catering to less demanding market segments are effectively engaged in concrete actions to adopt new generation technologies. The capital goods production system is formed by very heterogeneous companies, with extremely unequal capacity and skills.

Leading companies in the production of agricultural machinery operating in the country are an example of a success story, by offering Brazilian agribusiness producers integrated, connected and smart solutions to increase agricultural productivity and accelerate evolution towards precision agriculture. In spite of unfavorable domestic market conditions, machine tool manufacturers update their product line, thus adding connectivity to their equipment. The Brazilian leading company in electric motors invests in the development of electric motors for trucks and buses, hoping to explore a market niche in which the country seems to enjoy significant advantages. The presence of leading foreign and domestic companies with aggressive innovation strategies and capabilities ensures that the supply of capital goods keeps up with the movement of the international technological frontier in the most competitive industrial and economic systems.

However, for a large group of less sophisticated Brazilian manufacturers of electrical and mechanical machinery and equipment, keeping up with the technological frontier represents a serious challenge. They make up the most fragile segment in terms of capacity to transition to a new generation of technologies. Most of these companies are in a very incipient stage of developing equipment for new smart and connected manufacturing. The production and use of equipment for rigid or flexible manufacturing still prevail. Should this scenario continue to play out, the participation of these companies in the process of keeping up with the international frontier and producing updated equipment and solutions should be very restricted and lag behind.

The transition of this group of companies to more adequate levels of product modernization requires the participation of other companies with complementary technological assets, capable of developing shelf solutions to incorporate intelligence and connectivity into traditional equipment or to jointly develop new generations of equipment. In this regard, the participation of technology-based companies with competencies complementary to those of equipment manufacturers and that are integrators of digital solutions is critical. Technology-based companies that emerged in science and technology institutions are relevant players in the innovation generation and diffusion ecosystem, for keeping up with the technological frontier in ICT and capital goods as well as for promoting increased productivity and competitiveness in Brazilian industry.

3.5 Our challenges, risks, and opportunities

3.5.1 Common challenges, risks, and opportunities

Keeping up with the international technological frontier at a time of great change and rupture is not a simple task. It involves betting on technologies whose market selection process is still underway. However, Brazil can neither wait for the risks involved in the development and dissemination of new technologies to mature and decrease in order to promote diffusion among less qualified companies, nor have more qualified companies refrain from seizing opportunities.

The risk of not keeping up with the international frontier is that any shortfalls may disrupt part of the local production, especially in the case of capital goods, as well as create obstacles to the productivity leap of user sectors and cause Brazilian companies to miss new business opportunities.

Brazil does not yet have a solid initiative, such as the ones seen in the United States, China or Germany to reduce and share risks by acting as a mobilizing and coordinating mechanism of the technological development efforts of research institutions, equipment and component manufacturers, and clients. However, the time of changes in the technology landscape opens up windows of opportunity. New technologies can be catalysts of a new position of production systems that diffuse innovations.

From the perspective of the producers of goods and services involved in the diffusion of technical progress, technological change affords them opportunities to introduce new processes, resulting in efficiency gains and increased capacity to offer new goods and services that provide opportunities for business expansion and catching-up with international competitors. Likewise, companies in these industrial activities should prepare in advance for the reversal of the Brazilian economy investment cycle, when firms with installed capacity in new technologies will have advantages over those that will react only to the cyclical movements of the economy.

From the demand perspective, these technologies open up spaces for the renovation of the industrial park, productivity increase and improvements in product quality and differentiation. It should be noted that the markets for new solutions are expanding and their costs are falling rapidly. These two strong trends point to a process of accelerated diffusion of new technology-intensive goods and services.

The demand for digital technologies and/or capital goods (also with a high density of embedded digital technology) will be more likely to occur: (i) where the technical progress of the activity demands investments in complementary technologies, such as specialized and advanced knowledge activities (Aerospace & Defense, Oil Exploration, Pharmaceutics, Bioeconomics); (ii) where the investment in digital technologies to total investment ratio is low, as is the case in most producers of intermediate, process-intensive goods; (iii) where demand-driven markets are expanding and the propensity for investment is positive, in sectors such as capital goods, agricultural machinery and electric motors for heavy vehicles or for renewable energy equipment; and (iv) market niches associated with high knowledge-intensive services for growing markets such as agritechs and fintechs.

In this sense, Brazil's capacity to design and implement platforms that coordinate public and private initiatives to keep up with the rapidly shifting pace of the technological frontier, thus increasing both the number of companies involved and business opportunities, is a common challenge for the ICT and BK production systems.

3.5.2 Specific challenges, risks, and opportunities

3.5.2.1 ICT

The challenge of the ICT industry is to rapidly approach the production efficiency frontier and keep up with the technological frontier in specific market niches, especially where demand in the country is dynamic enough to afford business projects economic feasibility, with the local market serving as a learning and competitiveness base for expansion to other product and geographic markets.

On the production side, Brazilian equipment and component suppliers have no difficulty in providing frontier solutions, based on imported inputs rather than on a local supply chain. This trend should not change, except in segments where local demand justifies efficient production. This includes equipment in which the technical production scale is smaller (some sensor or large microprocessor segments).

Keeping up with the global technological frontier is feasible mainly in the ICT management and service software industry for specific economic activities in which there is proximity between solution providers and users. Advancing the diffusion of advanced technologies in Brazilian industry - a strong tendency according to the executives of the companies interviewed by the I2027 project team - requires that producers of ICT goods and services understand the needs of each user, since generic solutions do not always meet the demand. This opens up opportunities for digital ecosystems and spaces for companies and research centers with flexible capacity to develop specific solutions for their clients. These digital ecosystems, which are coordinated by solution (goods and services) providers, are multidisciplinary and can include integrators, research centers, and equipment and component suppliers. They will be more active where demand is more dynamic: in specialized and advanced knowledge activities (Aerospace & Defense, Oil Exploration, Pharmaceutics, Bioeconomics); and between producers of intermediate goods and inputs, such as agriculture, e-commerce, services (e.g. health and finance).

In addition to transformations in the business models and competitive strategies of companies, the servitization process and the growth of products associated with services point to the need of bringing producers and customers together, so that the former can effectively meet the peculiarities of innovation in services.

The development of innovative solutions goes through the design and development process in the country. This requires strengthening the national bases of product, system, component, and software design engineering as well as proximity to demand: user companies and/or through public contracts that address projects of relevant social interest. The simple assembly of components and equipment in the country while economically useful does not ensure the development of innovative solutions. These components/equipment need to be either integrated or the basis for specific solutions demanded by the Brazilian market, in order to ensure firm demand and minimum competitive production scale.

The software and service industries will gain more space because technologies such as IoT, AI, cloud computing, and big data analytics are software-intensive. Their characteristics, including those observed in a smart product/solution, point out the need for capabilities in areas such as systems engineering, IT security, software engineering, and data science. As the spread of IoT platforms advances, there will be opportunities for existing companies and startups, although the shortage of human resources in the country could be a serious bottleneck. The reformulation of engineering teaching programs emerges as a challenge to be met in the short term.

Current public policies for the ICT sector are still largely focused on import substitution. This requires implementing specific production processes in the country, although these are not always the most relevant in economic and technological terms. These policies need to be updated in order to further innovation (R&D), promote intense cooperation (including international) in innovation ecosystems and accelerate the diffusion of new disruptive technologies.

3.5.2.2 Capital Goods

The heterogeneity of the Brazilian capital goods industry points out a triple challenge to be met:

(i) Companies that have not yet achieved an efficient production capacity should shorten the distance between their current capacity and performance level and the production frontier. Smaller companies and simple equipment providers are technologically more likely to be at this stage of development.

(ii) Companies with efficiency levels, which are suppliers of equipment close to the production frontier and to the best product profile should remain in this position and advance in the development of innovative solutions (embedded digital technologies, new materials, and servitization).

(iii) Companies with innovation capacity should advance with the technological frontier by developing local providers and getting actively involved in innovation ecosystems, such as agricultural machinery or electric motor manufacturers.

The main challenge for the capital goods industry as a whole is to overcome the lagged and uneven dissemination of integrated, connected and smart production by accelerating its pace and expanding its reach beyond the group of leading companies, so that productivity gains can spread more widely across the productive structure.

The diffusion of the use of new technologies should be broad and rapid. The capacity to develop and disseminate knowledge and promote the use of new digital technologies needs to be strengthened. This implies establishing channels that facilitate the flow of knowledge among participants in innovation ecosystems.

Technology-based companies can contribute in this regard. Their competencies are complementary to those of the leading companies in the capital goods industry. Creating an environment in which the segment of technology-based companies can be continuously expanded and renewed is a way of accelerating and broadening the diffusion of digital manufacturing.

Brazil has already developed capacities to generate and disseminate knowledge in some of the technologies that support the advance of integrated, connected and smart production. It has groups of sophisticated researchers in several relevant areas of knowledge and companies in the BK production system and other systems, which are fully prepared to apply this knowledge.

The institutional capacity to mobilize and converge existing competencies in the country is a challenge to be met. In the absence of structuring initiatives in this direction, the dissemination of integrated, connected and smart production over a horizon of five to ten years should follow a rather limited and lagged trajectory in relation to the true potential of Brazil's economy and capital goods production system.

4

SPECIALIZED AND ADVANCED KNOWLEDGE ACTIVITIES: EXPLORING AND EVOLVING WITH THE INTERNATIONAL TECHNOLOGICAL FRONTIER

4.1 What are specialized and advanced knowledge activities?

This group includes the Aerospace & Defense (A&D) and Pharmaceutical production systems and the Deepwater Oil Exploration and Production (E&P) and Bioeconomics sectoral foci, which belong to the of Oil and Gas and Chemical production systems respectively.

Because of the very nature of the activities and their markets, the differences between these systems and foci are significant. Around 2013, direct and indirect investments in the oil and gas complex amounted to 15% of the total investment of the Brazilian economy. Since Brazil's oil and gas reserves are located far from the coast and at great depths, for them to be explored efficiently the main company in the sector - Petrobras - and service and equipment suppliers (para-oil industry) had to develop a highly sophisticated production and innovation ecosystem in Brazil. In A&D, Embraer is a world leader (technology, production and market) in the regional jet segment and its new KC 390 transport aircraft (military or otherwise) emerges as a promising leader in its market segment. Its innovation ecosystem is sophisticated, while the value chain is marked by a high degree of production internationalization. Bioeconomics is not exactly an industrial sector, but rather a concept to delimit a set of promising economic activities associated with low carbon economy and based on technologically sophisticated processing of raw materials that can increase the productivity levels of existing activities, as well as generate new products and create new markets. The Brazilian pharmaceutical industry, in turn, has been reaching stages of growing technological sophistication, from the increased production of generic medicines to pharmaceuticals derived from chemical synthesis or traditional biotechnology. Opportunities arising from biopharmaceuticals (with a strong emphasis on genomics) potentially open up new possibilities for expanding this trajectory.

Why, then, bring them together? Because they have in common four attributes of a technological and competitive nature and a particularity - in the Brazilian case, in terms of innovation capabilities and competitive capacity.

The common technological attributes are: (i) these are knowledge-intensive activities that depend on the results of the scientific and technological efforts of companies and of the innovation ecosystem with which they are associated; (ii) the innovations developed or absorbed and applied therein are not generic application technologies, as they have a specific purpose if compared to innovations generated in ICT and BK sectors; (iii) the pace of technological change is very fast; and (iv) competitive success is largely defined by the ability to differentiate products and services.

The particularity of these production systems and sectoral foci in the Brazilian case rests on the fact that most of the production, including in specific market niches, comes from companies with sufficient (actual or potential) competitive capacity and performance to challenge and even evolve with the international frontier.

4.2 What is the economic importance of specialized activities and what are the determinants of technological change?

4.2.1 Aerospace & Defense

This sector is marked by geopolitical interests and national policies of support for its industries, by fierce competition on a global scale in all segments and by intense technical progress. Such a combination of factors explains to a large extent the structure of the Aerospace & Defense production system, which is formed by few, although large, conglomerates concentrated in a few countries. End-product manufacturers hold the bulk of the industry's revenue and run global supply chains. In general, these conglomerates operate in both the civil and military sectors. The segment is led by the United States in both commercial and technological terms, followed by Europe. However, companies from China and Russia are increasing their international market share.

In Brazil, the production system is marked by the high share of the aeronautical industry, followed by the defense industry and a small share of the space industry - respectively 80%, 18% and 2% of revenues in 2015. Embraer, the world's third largest producer of commercial aircraft, accounts for more than 80% of the industry's revenue in the country. The local production chain is mostly made up of second and third tier suppliers, while top tier suppliers are located, for the most part, outside the country. The production system experienced a remarkable expansion between 2003 and 2015: revenues grew from US$2.5 billion to US$6.9 billion and the global market is the relevant market, since exports account for more than 80% of the sector's revenues.

Demand prospects for the segment dominated by Embraer are positive. However, the upcoming scenario is one of increased competition, due to the action of existing companies and the entry of new competitors. In order to survive and grow, the company will have to further strengthen the resource and skills base that has led it to stand out in the industry.

4.2.2 Oil Exploration and Production

This sectoral focus is subject to geoeconomic and political factors, to which the climate change dimension has been added. These factors have pushed oil and gas exploration and production (E&P) towards new frontiers, with emphasis on non-conventional resources such as shale gas, shale oil and tight oil - particularly in North America - and towards deepwater and ultra-deepwater exploration - especially pre-salt in Brazil. This is due to two main factors: first, the world economy is dependent on hydrocarbons (oil and natural gas), but navigates through scenarios of rapid depletion of traditional sources; and second, the costs of access to oil and natural gas reserves increase as the discovery of lower-cost reserves decreases.

Because of these determinants, advances in new frontiers have been significant. U.S. production increased from 6.9 million barrels a day (bbl/day) in 2005 to 11.6 million barrels a day in 2014. Brazil achieved capacity and specialization in the development of offshore oil resources over decades through industrial cooperation between oil companies, in particular Petrobras, and para-oil companies. The results are economically relevant: in 2016, 2.5 million bbl/day were produced and 798,000 bbl/day were exported, against 178,000 bbl/day of imports. Pre-salt production reached 1.42 million bbl/day in June 2017, having surpassed the production of post-salt fields.

If this trajectory continues, one can expect: (i) a weaker role of the Organization of the Petroleum Exporting Countries (OPEC); (ii) changes in the market structures of oil companies; (iii) a decline in the importance of petroleum as the guiding price of the world energy matrix; and (iv) a fierce competition for market shares that will further increase the need to seek a reduction in E&P costs through technological innovations. For producers, the reference for decision-making is the price level that defines the reduction or even the interruption of production in fields that are already active. The references are very eloquent: the strategic planning of global leading companies considers that the strong trend for oil prices is lower for longer or even lower forever.

E&P investment in the world has been slowly recovering in the recent past. The results of the 2017-2018 auctions in Brazil are indicative of this recovery. These results mean that a new wave of investments is expected to occur in Brazil over the next five to ten years. In this context, and despite prices having reached the level of US$65 in January 2018, oil companies are engaged in reducing the timeframe for project completion, extending the life of producing fields and, mainly, reducing CAPEX (capital expenditure) and OPEX (operational expenditure) costs. Therefore, the competitive success of companies in Brazil will be determined by the capacity of investments in gestation to incorporate new technological solutions and management tools in order to increase productivity gains and explore different cost reduction sources.

4.2.3 Pharmaceutics

The global pharmaceutical production system is knowledge-intensive: leading companies invest more than 10% of their net R&D revenue and all of them seek competitive leadership by launching new products. Currently, the structure of the Brazilian pharmaceutical industry mirrors the structure of the global industry. More than 500 companies compete for different market segments, but only a small group determines the industrial dynamics without, however, representing a high concentration rate. At the end of 2016, the four and ten largest groups had market shares of 22.7% and 43.3%, respectively. However, also similarly to the global level structure, considerable concentration rates are observed in different therapeutic classes and subclasses.

The pharmaceutical market in Brazil jumped from tenth place in the world ranking in 2011, with approximately US$17 billion, to eighth place in 2016, with US$28 billion. By 2021, it is expected to move to fifth place, with US$40 billion, behind only the United States, China, Japan, and Germany. From the supply perspective, the Brazilian market has changed a lot in recent years. While in 2000 nationally-owned companies accounted for 33.6% of total sales of medicines, this share rose to 46.3% in 2016. This development is related to the increased share of generic drugs in the pharmaceutical market. However, although they have grown and modernized, the main domestic companies are yet to achieve a relevant scale and scope vis-à-vis the global market.

Progress in this industry is determined by demand- and supply-related factors. On the demand side, population ageing and improved living standards in developing countries, coupled with the accelerated growth of health spending in developed countries and the consequent budgetary constraints of national health systems should leverage technologies that optimize the cost-effectiveness of medicines. In this sense, more and more the search for the cure rather than for the treatment of diseases should guide research in chronic diseases with therapeutic gaps. On the supply side, advances in genomics, proteomics, bioinformatics, and biomarkers will establish the concept of precision or personalized medicine as a generalized practice. A central constraint is imposed on advances: the ethical boundaries involved in the “repair and improvement” of parts of the human genome.

4.2.4 Bioeconomics

The economic activities associated with bioeconomics have, in common, the seizing of opportunities associated with low-carbon economy. The industrial exploitation of biomass for the production of biofuels, chemicals, materials, and energy is part of this process. Because of their scope, these activities do not exactly make up a production sector in its classic definitions (process or market similarities).

Companies of different sizes, origins and knowledge bases operate in these activities, seeking to explore and open up new markets, among them startups, leaders in the chemical and petrochemical industry, oil companies, agribusiness companies, food and ingredient producers, and paper and pulp companies.

Markets associated with bioeconomics are growing. While the production of traditional biofuels increases at an annual rate of 2.5%, advanced biofuels (even if still in the scaling-up phase) grow 10% a year. Although their annual production capacity is very low (around 1% of the global capacity of conventional plastics), bioplastics and bioproducts have proved to be economically viable in replacing their fossil-based counterparts. Production of these goods is expected to grow to 8 million tons by 2020.

The drivers of bioeconomics development are: (i) rapid advances of scientific knowledge in genetic engineering, fermentation processes, and enzymes, which contribute to the efficient use of biomass as raw materials and products; (ii) the climate change phenomenon and regulations arising therefrom, which make renewable raw materials feasible; and (iii) innovative pro-sustainability business postures.

4.3 What are the relevant technologies and their potential impacts?

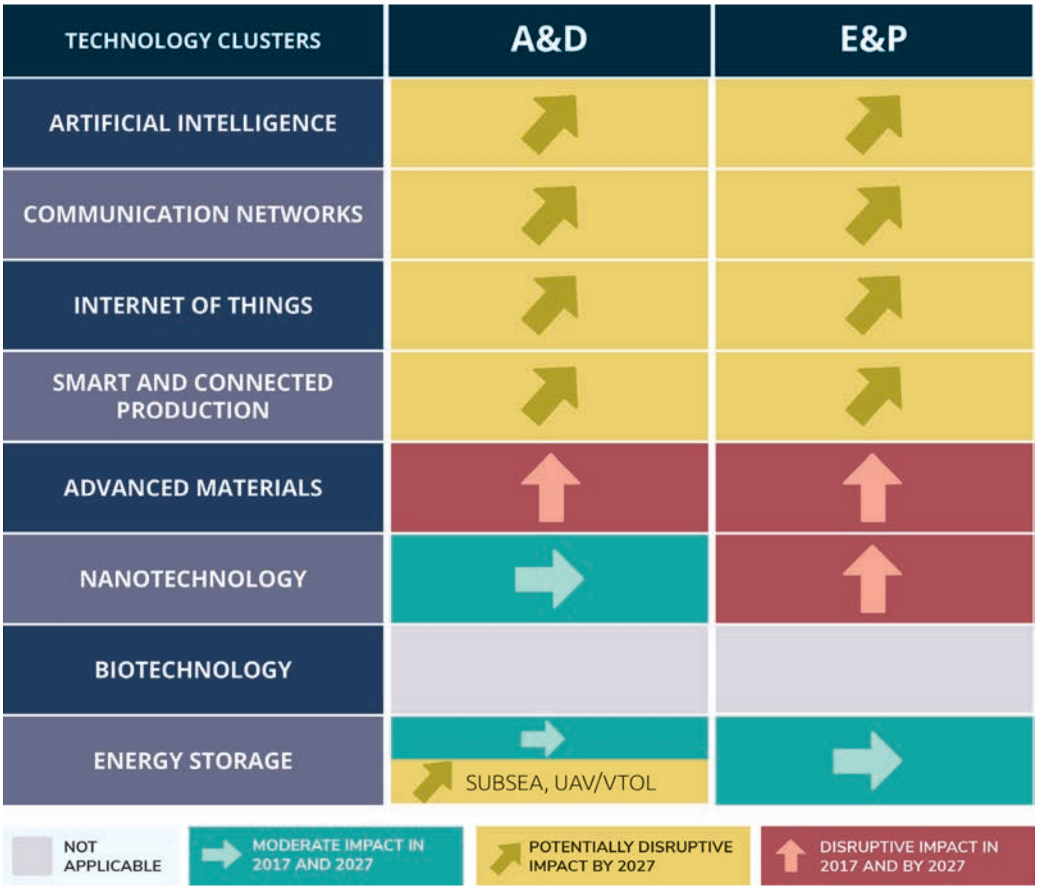
4.3.1 Aerospace & Defense and Oil Exploration and Production

The challenges are grueling in the segments in which Brazil stands out: in commercial aviation, the limits of energy efficiency, safety, and equipment durability need to be extended; and in the E&P segment, efficiency needs to be achieved in ultra-deepwater operations, in the logistics management of fields located 200 km from the coast, and in the disposal of gas flows with high concentrations of CO_2.

Technologies that will have a strong impact on A&D and E&P entail innovations in equipment and services, process innovations, and organizational changes. These technologies are of a similar nature, although specific solutions are naturally distinct: advanced materials, artificial intelligence, communication networks, IoT, SCP, nanotechnology, and energy storage. Some are mature and well-known technologies; however, they are mostly recent technologies without dominant technical standards. Also, in both segments there is a strong tendency towards servitization: users of A&D and E&P equipment require their suppliers to deliver goods and, increasingly, services of all kinds - from traditional maintenance to equipment operation.

Graph 8 shows the set of technologies with immediate disruptive impacts and the set of technologies which, within 10 years will result in changes in business models and competitive drivers. What is the meaning of these impacts? What changes do they bring to the companies, their suppliers and related innovation ecosystems?

Graph 8 – Relevant technology clusters: A&D and E&P



Source: Prepared by the I2027 project team.

Advanced materials technologies will have a disruptive impact on the A&D system and on E&P because they enable reducing the weight and increasing the resistance of materials used in equipment. This impact will be mainly due to the combined use of these materials with digital technologies. The use of composites is still in its early days, but the trajectory is clear: companies are testing new products and there is a strong trend towards hybrid models, with the combination of metal alloys for the production of parts and structural components. This trajectory will be facilitated by production automation and the use of additive manufacturing for the production of highly complex components.

AI and big data technologies will enable achieving high-definition imaging, creating 3D graphs and analyzing the performance of remote equipment, as well as improving man-machine interface and autonomous piloting. Network technologies will play a key role in the integration of communication platforms (air traffic control and network-centric warfare in the case of A&D and remote platform management in the case of E&P). IoT will enable capturing information through sensors and returning actions through actuators. Robotics, additive manufacturing and production virtualization, coupled with communication networks, IoT and artificial intelligence will enable achieving integrated, connected and smart production systems with a high level of automation.

In specific equipment such as military aircraft and unmanned aerial vehicles (UAV) and in subsea activities, the main advances should focus on technologies related to artificial intelligence, networks and IoT, which will allow for the detailed monitoring of equipment performance and improve man-machine interface. Also, new forms of energy storage will be decisive to ensure the longevity of vertical take-off and landing vehicles (VTOL), UAVs and subsea operations. Still in A&D, clusters of integrated, connected and smart innovations could result in the creation of the VTOL industry. An example is Uber Elevate - a project spearheaded by Uber with the participation of Embraer, Bell Helicopter, Aurora Flight Sciences, Pipistrel, and Mooney International Corp., support from the local Dallas (United States) and Dubai (United Arab Emirates) governments, and technical assistance from NASA.

In E&P, subsea operations, initially aimed at improving the interconnection of wells to production systems, are moving towards becoming subsea factories, thus mitigating the weight and space restrictions of offshore platforms. Petrobras estimates that the incorporation of underwater technological innovations would lead to a cost reduction of 35% to 40% compared to traditional projects. Outstanding key vectors of innovation and cost reduction include: autonomous and collaborative robotics; increased use of advanced materials and nanomaterials; enhanced imaging and seismic technologies to improve not only the decision-making process for the leasing of wells but also data interpretation capacity, and for the design of geological models of hydrocarbon generation, migration and accumulation; hardware/software integration and new models for data, information and new routine management, for making AI-based decisions.

Graph 9 summarizes the current and potential scope of technological solutions guided by the two challenges already mentioned: making new frontiers possible and at a low cost.

Graph 9 – E&P: trajectories, solutions, and trends

TRAJECTORIES	SOLUTIONS	TRENDS
Integration and interaction of new data generation and transmission technologies Process optimization with artificial intelligence and increased use of big data Data automation, generation and management, response-routine interaction Real time data	Shared production of equipment and services Horizontal wells Imaging and interpretation of geological data (fluid generation, migration and accumulation) Algorithms for seismic interpretation and identification of sweet spot cream and selection of location	Laser drilling Wells with nanosensors and smartfields 4D Seismic Smart completion: real-time monitoring of reservoirs

Source: Adapted from Pinto Jr. (2017)

4.3.2 Bioeconomics and Pharmaceutics

As in A&D and E&P, in Bioeconomics and Pharmaceutics the relevant technologies are similar, but different in terms of applications: new materials, nanotechnology, biotechnology, and digital technologies, in particular artificial intelligence and big data. Graph 10 shows the profile of these innovations. A quick look at the relevant technologies for Pharmaceutics could indicate that this is not a very change-intensive production system. However, the key technology of this system, namely new (genomic) biotechnologies associated with artificial intelligence and big data, is transforming business models, competition patterns, and market structures. In bioeconomics, biotechnologies also occupy a relevant transformational space. For manufacturing activities (biorefineries), IoT and smart and connected production emerge as potentially disruptive.

Graph 10 – Relevant technology clusters: Pharmaceutics and Bioeconomics

TECHNOLOGY CLUSTERS	PHARMACEUTICALS	BIOECONOMICS
ARTIFICIAL INTELLIGENCE	↗	↗
COMMUNICATION NETWORKS	→	→
INTERNET OF THINGS	→	↗
SMART AND CONNECTED PRODUCTION	→	↗
ADVANCED MATERIALS	↗	↗
NANOTECHNOLOGY	↗	↗
BIOTECHNOLOGY	↑	↑
ENERGY STORAGE	→	→

NOT APPLICABLE · → MODERATE IMPACT IN 2017 AND 2027 · ↗ POTENTIALLY DISRUPTIVE IMPACT BY 2027 · ↑ DISRUPTIVE IMPACT IN 2017 AND BY 2027

Source: Prepared by the I2027 project team.

In Pharmaceutics, empirical treatments give way to therapies based on the molecular mechanism of the disease, and interventions happen before and not after the disease is detected. These changes are enabled by technical progress and its convergences. Since the early 2000s, new molecular biology and genomic sciences have been advancing together with other technologies - such as bioinformatics, nanotechnology, regenerative medicine, artificial intelligence, and advanced imaging techniques - producing disruptive technologies for the health industries. The concept of personalized or precision medicine defines, to a large extent, the current development trajectory.

The technologies that drive the development of personalized medicine are described below. It is clear that progress in pharmaceutics is due to the integration between biotechnology and digital technologies:

(i) In genomics - genomic analysis to guide diagnosis and individual therapies.
(ii) In bioinformatics - AI and big data to guide and select R&D strategies and the development of leading compounds with greater focus and precision, thus saving time and resources at this stage.
(iii) In biomarkers - use of genetic biomarkers to stratify and establish dosages for patients according to their genotype or to identify those who will present adverse reactions[6].
(iv) In genomic engineering - genomic edition, a procedure that enables including, excluding or replacing DNA in the genome of living organisms or stem cells, by using artificially modified enzymes called engineered nucleases. It should be noted here that the discovery in 2015 of one of the families of these enzymes, the CRISPR/Cas9 system, or simply CRISPR, has great disruptive potential for the pharmaceutical industry.
(v) In automated diagnostic imaging - use of algorithms involving deep learning to analyze thousands of diagnostic patterns involving patient images.
(vi) In big data-enabled medicine - artificial intelligence analysis of multimodal data generated by research and diagnostic platforms. At the limit, the discovery of complex associative patterns can contribute to the development of new drugs, to the determination of environmental causes of human diseases and to making precision medicine possible.

Personalized medicine changes business models and the competitive bases of the pharmaceutical production system. Segmentation of populations will increase the relevance of laboratory diagnosis and its industry, hitherto relegated to the background by the one-size-fits-all dynamics. An increasing integration between the pharmaceutical and diagnostic industries is therefore expected. A second probable source of disruption caused by personalized medicine, with consequences for the pharmaceutical business model is related to the product lifecycle and to the management of product portfolios. As advances in the fields of genomics, biomarkers and bioinformatics reduce the costs and time required for the development and release of a new product, the number of releases of new drugs in the market will increase. Along this trajectory there will be therapeutic competition for the same clinical indication, that is, one drug may replace another as a reference for treatment, even during the period of validity of the patent

6 In clinical practice, biomarkers support the diagnosis by indicating the probability of an individual developing a certain disease, monitoring its evolution or indicating its prognosis.

that is being replaced. Companies with a focus on generic drugs may experience a strong negative impact, as the R&D process will become faster and less costly.

In the most probable scenario for a ten-year horizon, the current business model of the pharmaceutical industry will not disappear. Their leaders will continue their quest for profits through R&D and marketing of new medicines, with a view to reaching as many people as possible, with the greatest possible market potential. However, a hybrid system will very probably be established, in which traditional big players will have to coexist with new entrants with business strategies that match the concepts of personalized medicine.

In bioeconomics, progress will depend on the coevolution of progress in raw materials, in biomass treatment and conversion processes, and in products and business models. At present, great efforts are being made in biorefineries with the aim of obtaining productive processes (either fermentative or enzymatic, using or not synthetic biology) capable of converting biomass with high levels of efficiency. The scenario is one of a large number of innovative projects competing with different solutions, in response to opportunities identified by innovative companies, whose knowledge bases will be associated with advanced biotechnology, including synthetic biology. These are startup projects supported by the promotion of innovation policies, with venture capital funds and investments from companies established in several industries. Graph 11 shows the probable evolution of processes associated with bioeconomics.

Graph 11 – Evolution of industrial processes associated with bioeconomics

	1ST GENERATION PROCESSES	2ND GENERATION PROCESSES	BIOREFINERY OF THE FUTURE
INDUSTRIAL STRUCTURE	Known	In the structuring stage	To be shaped
DRIVER	Cost	Cost and differentiation	Cost and differentiation
MARKETS	Commodities	Commodities and specialties	Open
TECHNOLOGICAL STAGE	Mature	Start of commercialization	Laboratory/pilot/demo

Source: Adapted from Bomtempo (2017).

4.4 Where are we now and where are we headed? Relevant technologies in companies

4.4.1 A&D

In A&D, the processes of generation, use and diffusion of innovations are concentrated in Embraer. The company is an international reference in the use of digital technologies in projects and production and develops multidirectional innovation efforts: cross-sectional, vertical and diversifying.

These efforts are characterized as cross-sectional according to the implementation of AI, networks, IoT and SCP. Digitization started in product engineering ("digital airplane") and its expansion is oriented towards the production process ("digital factory"), through the establishment of the Virtual Reality Center (CRV). Still in processes, the company has advanced in the use of robots and automation of structural assembly and in stages such a painting, manufacture of the interior of the aircraft and movement of tools, and is initiating efforts in additive manufacturing and enhancing its capacity in new materials technologies. These innovations aim to reduce errors to virtually zero in aircraft manufacturing.

In its main market - regional jets – in 2011 the company decided to remain in the mid-range twin-engine jet segment, designing new generation equipment with 17% less fuel consumption than the previous generation, thus reducing emissions and enabling flying greater distances. The equipment was homologated by three agencies (Brazil, U.S. and Europe) simultaneously, and the first aircraft was delivered in April 2018. To a large extent, new engines, wing design and fly-by-wire system provide efficiency gains.

In the verticalization process, the company is reinternalizing activities previously commissioned from third parties, while undertaking geographic diversification efforts with assembly plants in Portugal and the United States, for different purposes. To pursue servitization the company is introducing AI and big data in aircraft maintenance and machine learning processes to automate the classification of events occurring in the fleet. At the same time, it can be said that the value chain located in Brazil is still very fragile, as it is limited to second or third tier suppliers. Advancing this value chain is a challenge to be met.

The most recent diversification efforts are focused in the area of transport, with emphasis on the military segment. The company is introducing an aircraft (KC-390) with cost and performance features capable of catering not only to the defense area but also to market niches with high growth potential. At the same time, the company is starting efforts for the production of fighters, in partnership with the Swedish company Gripen. This is requiring the requalification of personnel and the introduction of production processes specific to the design of the equipment. In partnership with other companies, including Uber, the company is investing in developing the VTOL market. The company plans to start testing the equipment in 2020 and begin commercial operation between 2023 and 2026. These opportunities, if properly harnessed, will open up new areas of growth for the company.

4.4.2 E&P

Investment and operations in the Brazilian oil and gas system have been marked by cooperation between oil and para-oil companies, universities and research centers, whose most outstanding feature is the Technology Park on Fundão Island, on the campus of the

Federal University of Rio de Janeiro (UFRJ). These cooperation efforts, which have resulted in the establishment of a unique productive and innovative sector in the country and in the world, have been essential for the successful search for technological solutions to the challenges inherent in oil exploration in Brazil.

These cooperation efforts have resulted in a broad range of technological solutions and innovations for the challenges of Brazil's offshore production: 3D seismic - now 4D - that influences the success rate of exploratory and development wells; deepwater drilling technologies; horizontal drilling, with the consequent reduction in the number of wells and 30%-40% increase in recovery rates; semi-submersible platforms and floating production storage and offloading (FPSO) vessels with a dynamic positioning system; and new materials capable of withstanding high pressures.

Underwater technologies for oil exploration and production are not new, since they are already being used in the Campos Basin production fields. However, there is a strong trend towards increasing the number of equipment items installed in the underwater bed, in order to overcome the physical restrictions of fixed platforms and FPSO. In these equipment items, the increased number of embedded equipment led to the competition for space and weight with oil storage tanks, due to the size of the production systems. The solution, therefore, is to "unload" systems into the underwater bed. Likewise, the progressive complexity of subsea solutions, whose initial objective was to improve the interconnection between wells and production systems, now requires the integration of different technologies for information support, connection, monitoring and generation. This integration is evolving into subsea systems. Advances in this direction are promising. An example is the latest generation of manifolds produced by TechnipFMC that incorporate new materials, electronic and robotic components and have succeeded in reducing their average weight from 250 to 100 tons. Lighter equipment facilitates movement and the incorporation of robots enables minimizing subsea equipment maintenance activities. In case of repair, just the robot needs be changed, instead of the entire manifold.

The technological complexity of oil and gas exploration operations under Brazilian conditions imposes entry barriers not only for medium and small-sized oil companies. Probably more important are entry barriers for new producers of underwater equipment and technologies. This market has been known for increasing industrial concentration and strengthening the oligopolistic condition of leading companies through important mergers and acquisitions, such as the merger between Tecnhnip and FMC (TechnipFMC) in 2017 and the expected merger between GE and Baker Hughes.

The productive and innovative ecosystem and the value chain of the oil industry in Brazil are relatively sophisticated. The main players in the industry are present in the country, but lack of investment in the recent past has led to the demobilization of important assets, particularly in the Technology Park on Fundão Island. This time is almost over; the resumption of investments will come in a relatively short time, but with frameworks quite different from those observed in the last investment wave: low cost and high levels of compliance with specifications. This framework can only be achieved through the results of high investments in science, technology and innovation. This is the main challenge for E&P companies.

4.4.3 Pharmaceutics

The three groups of pharmaceutical companies operating in Brazil have different capabilities, will experience impacts and will have different opportunities due to technological transformations and current demand pressures: (i) large global companies with R&D activities in parent companies and/or close to leading technology centers (research in the country is restricted to clinical research); (ii) nationally-owned companies whose focus is currently restricted to generic production; and (iii) large nationally-owned companies with diversified portfolios, including generics and similar medicines and prescription medicines.

The Brazilian pharmaceutical industry has adequate production capacity, as well as capabilities for process optimization and introduction of new products. In fact, Brazil's industrial park was modernized after the introduction by ANVISA of regulations providing for compliance with and inspection of good manufacturing practices.[7] Pharmaceutical companies have the necessary capacity to produce solid, semi-solid, liquid, hormonal, and injectable medicines based on best practices. Several companies have the necessary competencies to promote incremental innovations, based on technological platforms. Artificial intelligence algorithms, associated or not with big data, are already being tested to improve the productivity of pharmaceutical R&D. New materials associated with nanotechnology techniques have already been used by the industry, especially in devices for differentiated drug release. In relation to radical innovations, however, only a smaller group of companies has already internalized R&D structures and established partnerships in Brazil and abroad for the development of new products.

In biopharmaceuticals, the inclusion of Brazil is not recent. For a long time, official laboratories such as the Butantan Institute and the Oswaldo Cruz Foundation have been producing vaccines and other biological products. Since 2003 the Oswaldo Cruz Foundation, through Bio-Manguinhos, has had a technology transfer agreement with Cuba for the production of first generation biopharmaceuticals. Biobrás produced insulin of animal origin on an industrial scale from 1983 to 2002, when Novo Nordisk acquired its operations. The creation of Bionovis in 2009 can be considered a landmark in the resumption of modern biotechnology in the country. Six companies are engaged in biosimilar segments: Biomm, Bionovis, Cristália, Libbs, Orygen, and Recepta. This group of companies can generate up to R$2 billion in revenues by 2020. Biosimilars represent a window of opportunity for qualified companies to further internalize biotechnology capabilities and, in an optimistic scenario, serve as the basis for the development of innovative biopharmaceuticals in the medium and long term.

7 RDC No. 275, 2002 and RDC No. 17, 2010.

4.4.4 Bioeconomics

In Brazil there is a wide spectrum of companies in activity with active strategies in industrial biotechnology and in various stages of development. In or close to the commercial stage there are initiatives in green polyethylene, 2G ethanol, oils and derivatives of heterotrophic microalgae, and chemical specialties. R&D projects are also underway at pilot or demonstration scales in butadiene, isoprene, mono-ethylene glycol (MEG) made directly from sugars, cellulosic sugars, bio-oil, nanocellulose, lignin, and carbon fibers among others. Also noteworthy are some business initiatives aimed at the development of new groups of raw materials and special products based on Brazilian biodiversity. Advances of companies in bioeconomics are facilitated by the existence of research institutes, with a focus on capacity-building for the development of processes and products in partnership with companies such as CTBE, CTC, Embrapa Agroenergia and three SENAI Innovation Institutes (biomass, biosynthetics, and green chemistry). The level of cooperation between companies and research institutes is unprecedented in previous development cycles of the Brazilian chemical industry.

Economic activities associated with bioeconomics vary in terms of origin of the companies, type of processes and products of interest, and stage of development. This stage is not different from the one found in the international scenario and most of these initiatives are close or very close to the introduction of innovations of frontier processes and products. Most importantly, bioeconomics prospects are promising, and Brazil's current position for future progress is driven by business interests, investments already made, and accumulated capabilities that are unique and indispensable assets for any future developments.

4.5 Our challenges, risks, and opportunities

4.5.1 Common challenges, risks, and opportunities

Aerospace & Defense, Oil Exploration and Production (in the Brazilian case), Pharmaceutics and Bioeconomics correspond to economic activities in which competition occurs through innovation and the capacity of companies to shape markets. Relevant technologies include advanced materials, nanotechnology, and biotechnology. Digital technologies, especially artificial intelligence and big data, are essential because they enable specific technologies and themselves (IoT, smart production, and high-performance networks) to make relevant contributions to product efficiency, quality and differentiation. And these technologies, if not yet disruptive, will be so within no more than ten years.

In these activities, as in any technology-intensive activity, companies compete for new products and processes and the successful ones are part of productive and innovative ecosystems that bring together universities, research centers, and component, equipment, and service suppliers. The closer different players are, the stronger these ecosystems will be, especially to enable efficient flows in the value chain, and in the case of technological development regardless of how much high-performance communication networks and efficient logistics systems can make activities possible in a situation of geographic dispersion.

In A&D, E&P (in the Brazilian case), Pharmaceutics and Bioeconomics, Brazilian ecosystems - given the already accumulated capabilities and proven competitive performance - can contribute to evolution alongside the international frontier. This is a unique situation: on rare occasions in its history and within a context of intense technological change, Brazil had a large enough stock of entrepreneurs, researchers, investments, and accumulated capabilities to face technological and competitive challenges. Given the capabilities and positions of companies and research institutes, advancing, exploring and pushing frontiers requires monitoring opportunities and planning investment in innovations, including those that have a long time-to-value and are made in a developing technology environment.

Seeking international technological leadership is a difficult skill for countries, innovation ecosystems, and emerging companies. It requires the ability to develop scientific and technological capabilities, often in new areas still under construction, as well as prospective economic evaluation capacity and great innovation management capabilities. This is a particularly critical challenge for policymakers in the industrial and financing areas as well as something valuable for business decisions. Having sectoral knowledge associated with scientific and technological bases is a strong prerequisite. It is essential to "understand" technological and competitive trajectories and challenges. And it is essential to be willing to invest in the long run and be ready for both success and failure in innovation, but always with a long-term vision, which can be particularly difficult given Brazil's lack of experience in participating in technological races.

4.5.2 Specific challenges, risks, and opportunities

4.5.2.1 Sectoral focus: A&D

The convergent emergence of new technologies that are relevant to Aerospace & Defense represents a unique opportunity and is in line with a strategy for Embraer not only to consolidate its position as the world's third largest aircraft manufacturer, but also to expand its activities in the military and system control segment as a leader in specific niche markets, and diversify into new segments such as the urban autonomous aerial vehicle project. The challenges can be met because they are related to areas in which the company is highly-skilled: design, especially of new aircraft models; advanced aircraft integration and production with the combined use of advanced process and product materials in and efficient management of a productive and innovative ecosystem.

Ongoing technological changes will affect this ecosystem. The modest structure of suppliers is expected to change as a result of the growing importance of integrating electronic and digital technologies in the segments of physical parts and components, which will also change towards new materials. In value chains, the metal mechanics segment, where most national suppliers operate, will lose importance to producers of new materials. Specialized suppliers will need to address the company's re-internalization strategy. However, new opportunities will emerge for companies that are skilled in new technologies, especially integration and materials engineering companies that may wish for the position of first-tier suppliers. Negotiations with Embraer's international partners should focus on strengthening the innovative and productive capacity of the local ecosystem in segments where the company stands out, as opposed to the company's own internationalization process.

These are the paths to consolidate and enhance technological leadership in A&D segments, in which Brazil stands out. The more internationalized Embraer becomes, the stronger the productive and innovative Brazilian A&D ecosystem will need to be, so that the company's competitive density can be maintained and increased. This means strengthening and enhancing local competencies (sector research center, CTA, Aeronautical Institute of Technology - ITA) and, above all, strengthening a system of networks of research institutes that can contribute to relevant technologies in this industry, such as some of SENAI's innovation institutes (embedded systems and basic metals and special alloys, for example). In this environment of rapid technical progress and of uncertainty as to the innovative solutions that will be selected by the markets, it is essential to sustain the leading company by investing in new competencies in human resources and research institutions.

4.5.2.2 Sectoral focus: E&P

The challenges and opportunities in E&P are similar to those in A&D, but in the latter, there is a difference between value chains and productive and innovative ecosystem. New and convergent technologies offer the opportunity for achieving competitive costs in highly complex offshore oil and gas exploration processes. In an environment of new competitive frames of reference and intense technological change, the existing resource base must be expanded and renewed in a low-cost structure, in order to consolidate and strengthen Brazil's leadership in offshore E&P. Among oil companies, the leading role hitherto played almost exclusively by Petrobras will be shared with other companies (world leaders). The economic importance of Petrobras will remain unchanged. However, for the company to continue to stand out among its peers, its production and innovative agenda must keep up with ongoing technological changes. In this context, the competitive process itself should impel Petrobras to maintain its role as a benchmark for complex E&P solutions, while Brazil needs to learn new relationship and investment practices from new incoming investors.

In the productive and innovative ecosystem, para-oil companies are also relevant protagonists. They are a necessary gateway between solutions emanating from or demanded by oil companies, other suppliers and research institutes. Therefore, these companies are moving towards: (i) seeking possible and adequate technological solutions; (ii) changing the profile and specification of resources (equipment and people) by introducing new technical bases (new materials) and advanced and additive manufacturing; and (iii) building capacity in servitization, from equipment maintenance to operation, which may also imply shared ownership of processes.

Nonetheless, the supply chain will be reorganized, probably towards the (i) re-verticalization of parts and components; (ii) integration with digital technology providers; and (iii) emergence of small specialized suppliers (startups).

An asset that Brazil has built and which has contributed in recent decades to the competitive success of offshore E&P is the teaching and research infrastructure directly or indirectly associated with oil. The under-utilization of these competencies in the years of investment recession in the country is coming to an end, in view of new expansions of production capacity already defined by the commitments of oil companies in the latest auctions. Renewing this infrastructure based on new technological and competitive framework (from the perspective of oil companies) is a structural challenge to be met.

4.5.2.3 Pharmaceutics

Brazil's pharmaceutical industry can keep up with and explore niches in the technological frontier. Preventing companies from losing the competitive edge they have achieved and enabling them to move forward will require embracing new technology trends and intensifying innovative efforts, with a view to building higher value-added portfolios outside price competition. Bringing Brazilian industry closer to its international peers is a possibility. The emergence of new technological fronts, the consolidation of the personalized medicine concept and increasing pressures on the demand side provide opportunities for companies to move towards the technological frontier in health.

For the pharmaceutical industry, Brazil's accelerated demographic transition is a unique opportunity. However, the evolution of the national pharmaceutical industry will require overcoming institutional challenges to consolidate a robust productive and innovative health ecosystem in Brazil. For each of the three different groups of pharmaceutical companies operating in the country, demand and technological pressures have different implications, which must be recognized when developing and implementing business strategies and public policies.

In the case of the group of foreign-owned companies with operations in Brazil, if they follow the past trajectory the answer will come from imported products and solutions. However, the advance of personalized medicine will require investments in innovation in the country. For nationally-owned companies with a focus on generic drugs, new technologies are a major threat. The advance of biotechnologies and health-related information technologies will contribute to reducing the time and cost of discovering and developing a new drug. Generic drugs can be replaced by innovative, low-cost ones. However, the organizational capacity of these companies affords them the necessary flexibility to adapt, as long as they recognize the need to enhance - and actually do enhance - their innovation efforts. For the third group of companies - nationally-owned companies with a diversified portfolio, little dependence on generic drugs and bioequivalence capabilities - the risks and opportunities are different. The emergence of new technological fronts, the consolidation of the personalized medicine concept and increasing pressures on the demand side with high impact potential, afford companies sufficient potential to advance, and it is reasonable to believe that they have a real possibility of being closer to the technological health frontier.

4.5.2.4 Sectoral focus: Bioeconomics

In bioeconomics, the lack of a well-established market structure provides Brazil an opportunity to exploit its comparative, competitive, and innovative advantages. Although some segments, such as synthetic biology require a catching-up strategy, the use of renewable biological resources presents an important local specificity, suggesting that Brazil has the possibility of both pushing the world's frontier in innovative best practices and shaping markets.

Some challenges must be addressed: (i) enhancing the scientific, technological and operational knowledge base in industrial biotechnology and, in particular, synthetic biology; (ii) structuring a long-term supply of biomass, based on productivity, availability, quality, cost, and environmental performance requirements of both the company and the logistic supply chain; (iii) diversifying the renewable materials base by developing technology and logistics packages for new raw materials, exploiting the potential of biodiversity for special raw materials (for cosmetics and other high value-added uses), and structuring knowledge about the Brazilian potential in biomasses associated with urban, agricultural, and agroindustrial waste; (iv) investing in scale-up and operating new processes, particularly those involving advanced biotechnology; and (v) promoting the diffusion of new products.

Special mention should be made of the challenge related to raw materials and processes, given the advances already made in Brazil. The country's main comparative advantage lies in agricultural productivity, especially sugarcane and planted forests. However, there are challenges related to the current stage of productivity that will need to be addressed in the coming years and to the development of new products such as energy sugarcane, which are more suitable for the requirements of innovations in Bioeconomics. The potential of biodiversity for special raw materials also remains open. Structured knowledge of Brazilian biomes is essential for the development of bioeconomics. With regard to processes, the country is still facing challenges related to conversion, pretreatment and process engineering technologies. Designing and operating an industrial plant using processes based on synthetic biology has been a great challenge for the pioneers. Achieving technologies capable of competitively providing sugars from lignocellulosic materials or other starting materials, such as cellulose and lignin, is decisive for the development of the industry.

A basic condition to facilitate the structuring of productive enterprises in bioeconomics is to advance in carbon pricing through the market or taxation. This is a relevant and priority public policy agenda to be developed in partnership with the private sector.

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5

PRODUCERS OF INTERMEDIATE INPUTS: KEEPING UP WITH THE PRODUCTION FRONTIER AND EXPLORING SYNERGIES WITH COMPETITIVE SECTORS

5.1 Who are the producers of intermediate inputs?

This group includes the production systems or sectoral foci associated with Petroleum Refining, Chemicals, Basic Inputs, including Iron and Steel, and Agricultural Commodities.

These are very different economic activities. Petroleum refining is concentrated in one company and its product is primarily destined for the domestic market. The chemical industry depends mainly on petroleum products, which are produced by Petrobras, and has a high degree of heterogeneity and diversity. Alongside companies of size and competitive capacity compatible with international industry, some medium and small companies are still lagging behind. Basic inputs (iron and steel, mining, basic metals, cement, ceramics, glass, and cellulose pulp) are distinguished by factors such as commercial purpose - domestic versus export market – inclusion in production chains, efficiency, growth rate of demand, and usage level of installed capacity. Agricultural commodities are characterized by primary producers, processing stages and distribution logistics. The country is the world leader in sugar, coffee, orange juice, and red meat exports, and ranks second in soya and poultry exports and fourth in pork exports.

Why, then, bring them together? Producers of intermediate inputs have in common at least one of five technological and competitive attributes and one particularity, in the Brazilian case in terms of competitive capacity.

The technological and competitive attributes are: (i) high capital intensity and continuous processing of production and/or position in the links upstream global value chains; (ii) the main technological innovations come from outside the sectors, since these are activities that benefit from technical progress generated outside them; (iii) the pace of technical progress is relatively slow and to a large extent the transformations occurring within them are essentially incremental; and (iv) the products are relatively homogeneous, so that process innovations are central for competitiveness, whereas production efficiency (revealed in low costs per unit of product) and compliance with specifications define the competitive advantages of companies competing for markets that in general are highly concentrated.

In the case of Brazil, these production systems and sectoral foci have a distinct particularity: in most of these activities much of the production is in companies and production chains with competitive capacity and performance revealed by their exporting performance and cost advantages stemming mainly from privileged access to raw materials. Maintaining these competitive advantages, keeping up with the international production frontier - of both efficiency and quality - is the challenge facing producers of intermediate inputs. In some specific niches, Brazilian companies may even explore frontier technologies. The capabilities accumulated in productive and innovative ecosystems in the intermediate goods industry, when added up and renewed by new technologies, afford a unique opportunity for companies to position themselves competitively and sustainably in their markets.

5.2 What is the economic importance of intermediate inputs and what are the determinants of technological change?

5.2.1 Refining

Two important transformations are underway in the refining industry - one associated with the characteristics of the industrial processes and another of a locational character.

From the technical standpoint, the mix of derivatives in refining is not yet flexible enough to maximize or prioritize the production of a specific derivative in relation to others. Nonetheless, companies try to "push" technical constraints to the maximum by investing in modernization and flexibilization, in order to increase processing throughput and the qualitative profile of derivatives. This happens because the participation of heavy oil in the refined mix is increasing, as is the need to produce light and medium derivatives in response to the demand profile.

From a locational standpoint, in the European Union and Japan, demand declined between 2005 and 2015 at an average rate of 1.7% and 2.5% per year, respectively. This decline in demand, especially in the case of gasoline and diesel, is due in part to the modest role of biofuels, to urban mobility alternatives, to high prices between 2004 and 2014, and finally to energy regulatory and policy measures aimed to replace fossil fuels.

These trends had repercussions for the supply structure. After a period of growth of crude oil processing capacity in the refineries until the end of the 1990s, significant changes have occurred in the last two decades. The capacity of the European Union, which in 2006 was 16 million barrels per day fell to 13.9 million barrels per day in 2016. At the same time, both demand and production capacity have grown in China, India and the Middle East - basically in Saudi Arabia. Of the total increase in global refining capacity between 2010 and 2016 - 4.84 million barrels per day - China accounted for 53.1%, an increase of 2.6 million barrels per day. This increase is equivalent to the total Brazilian capacity.

By the end of 2015, Brazil had 17 refineries with capacity to process 2.4 million barrels of oil and other cargoes per day. Petrobras practically has the monopoly of the activity, with 13 of these units and 98.2% of national capacity. This market power has implications for the process of price formation of derivatives and for the conditions for other agents to access the industry. However, most of the Brazilian refinery park - mainly larger refineries - was built long ago. But this does not mean that their processes date back to the time of their inauguration. Over time, and especially in 2010, important investments have been made to upgrade process controls. The emergence and the recent diffusion of advanced digital technologies opens up opportunities for the modernization of this production park.

5.2.2 Chemical

Global sales by the chemical industry in 2016 totaled some US$3.7 trillion, with China and Latin America accounting for about 40% and 3.8% of this total, respectively. Most chemicals (75%) are sold as intermediate products, with 26% destined for the chemical industry itself and 49% for other sectors. Products sold directly for final consumption (25% of the total) belong mainly to the pharmaceutical and agrochemical industry. As a production system, the global chemical industry (excluding pharmaceuticals and petrochemicals) has a fragmented structure, with very low concentration rates: in 2014, the top 50 companies accounted for only 18% of sales. Among the main companies, 17 are headquartered in Europe; 12 in the United States (four of the ten leaders); eight in Japan; and four in South Korea. Braskem, the only Brazilian company to make the list, ranks 14th in terms of sales, with 0.36% of the world market. Sinop is also the only Chinese company on the list.

The Brazilian production system ranks eighth in the world. Sales in 2016 totaled US$113.5 billion, about 3% of the world total. The share of GDP between 2008 and 2015 remained around 2.5%. Considering industrial GDP, the chemical industry ranks third, after food and beverages, oil and fuel and ahead of the auto industry. However, from the standpoint of the trade balance, in recent years the industry has endured large and growing deficits, which in 2016 reached US$22.1 billion. In the last ten years, this deficit has been determined by the variation in imports, since exports have remained stable and even declined since 2008. In terms of the nature of the products traded, 54.9% of the sales are destined for the industrial sector. The Brazilian chemical industry is more concentrated compared to the global market. In 2016, the four largest domestic companies held 14.61% of the market.

In 2015 the global petrochemical market was valued at US$419.4 billion. The industry's growth trajectory is determined by the demand for its derivatives in the automotive, textile, construction, industrial, medical, pharmaceutical, electronics, and consumer goods industries. The petrochemical industry is mature from the technological point of view. Since the 1980s the industry has followed a consolidation trajectory, with modest growth rates. Therefore, this industry is concentrated in large, capital-intensive companies with strong barriers to entry and cyclical movements of investments, prices, and profit margins. The main competitive factors are production scale, access to quality raw materials at a low cost, integration to achieve economy of scope, and cost advantages.

In resin production, competitiveness may also depend on the effort towards product differentiation. In these cases, relations with end users (automotive and electronic industries) are critical to competitiveness. From the standpoint of its main products - high consumption resins -, the industry can be considered little innovative. However, efforts to develop and adapt grids to specific use conditions should not be disregarded. With respect to specialties, the competition pattern is different. Product innovation and differentiation (whether market-oriented or for specific functions) is becoming increasingly important. These products are used in specific applications in industries such as electronics, petroleum, mining, and agriculture and are developed for a function or with properties that define and identify them: adhesives, antioxidants, aromas, fragrances, etc.

Similar to the refining industry, in the recent past petrochemical production has been shifting to nations with market growth potential such as Asian countries, particularly China, or countries with a favorable position in raw materials, oil, and natural gas. Thus, in this century expansion projects in Northern Hemisphere countries are very rare. However, this trend has been revised due to the availability of low-cost natural gas in the United States, which has led to the re-emergence of first- and second-generation petrochemical investment projects in the United States.

Industrial plants in the Brazilian petrochemical industry have competitive scales and are considered modern in both technological and operational terms. Their main disadvantage is lack of access to quality raw materials at competitive prices. The recent international conditions of natural gas supply at low prices in the U.S. market further reduce the industry's competitiveness.

With regard to specialties, the most important segment is pesticides, with Brazilian demand representing 20% of the world market. This market is served by large international companies: Syngenta, Bayer, and Basf, which cover about 70% of the market, while 30% is served by generics producers. The search for low-carbon agriculture, the use of better and more modern pesticides, innovations in biological pest control, and precision agriculture make the segment a target of major transformations. The emergence of numerous startups and the evolution of both incumbent and challenging business models illustrate these transformations. Four other segments should be highlighted due to their dynamic growth and potential to incorporate innovations based on renewable raw materials: lubricants, chemicals for the oil and gas industry, food and feed additives, and aromas and fragrances.

5.2.3 Basic inputs

The markets for basic inputs are concentrated and the products are homogeneous. The main barrier to entry stems from incumbent economies of scale, although there may be significant differences in each segment. Technical progress is slow, innovations are incremental, and the competitive advantages of companies derive from cost advantages and their capacity to meet technical specifications. When production involves high volumes and markets are located at long distances, as in the case of iron mining and even of cellulose pulp, a significant portion of the investments goes to logistics (railways, ports). Efficiency in transport logistics can be decisive for companies to secure cost advantages.

Between 2005 and 2015, the production of basic inputs increased its share of the industrial transformation value (VTI) worldwide. The basic metals (steel and aluminum) industry increased from 9.8% in 2005 to 10.7% in 2015. Non-metallic minerals (ceramics and glass) grew from 5.2% to 5.5%. This trajectory is expected to continue in the coming years, and certain minerals (lithium and cobalt) are expected to grow at even higher rates, due to the demand for electric vehicles. Pulp is growing at rates of approximately 3%, especially short fiber pulp, and the level of use of the pulp industry's installed capacity is high (93% in 2017), when compared to other basic inputs such as the steel industry (69% in 2016).

As in the case of other commodities, in basic inputs there is a strong trend towards reducing the relative importance of developed nations in the generation of sectoral VTI. In basic metals, this value decreased from 76.4% in 2005 to 64.7% in 2015. A similar trajectory was observed for non-metallic mineral products (79.8% to 68.3% respectively). Similarly, pulp and paper decreased from 77.3% in 2005 to 64% in 2015. In this industry, the top five producers in 2016 were the United States, Brazil, Canada, China, and Sweden. In cement production, plants tend to have a high vertical integration, especially because cement is a low added value product in terms of logistic costs. In 2016, China's share of global clinker capacity and global cement production was 54.1% and 57.4% respectively.

The structural situation of the steel industry is complex (and not only because of the recent action taken by the U.S. government). This is an internationally widespread activity, in which 94 countries produced 1.63 billion tons of crude steel in 2016 to meet a demand for 1.52 billion tons. Since 2010, Chinese demand for steel has oscillated around 45%. In production, in 2016 the market share of Asian countries - with the exception of China - reached 19.5%. China's share rose from 15.1% in 2000 to 49.6% in 2016. The 28 European Union countries accounted for 9.9%, while the share of NAFTA countries was 6.7%. Steel production in South and Central America accounted for 2.5% of global production in 2016. Considering that the current installed capacity totals 2.39 billion tons of crude steel, there would be no need to expand the existing industrial park over a period of five and ten years to supply global demand. On the external front, world exports of slabs, blocks and billets (where Brazilian foreign sales are concentrated) fell from 58.7 million tons in 2010 to 51.1 million tons in 2016. These facts are evidence that for a long time to come, the steel industry will continue to face significant imbalances between supply and demand.

5.2.4 Agricultural commodities

The agroindustrial production system holds a significant share of the industrial product of most countries (between 10% and 30%). World food and beverage production alone is estimated at US$4 trillion, generates 25 million jobs and is concentrated in high-income countries (two-thirds), although these countries are home to some 16% of the world population. However, countries like Brazil, India, China, and Russia are already the most dynamic markets. The top 100 multinationals produce about 38% of the world total and stand out in terms of innovations.

Agribusiness accounts for approximately 23% of Brazil's GDP - a larger share than in the United States, where it is below 10%. Agribusiness reached R$1.4 trillion in 2016, of which R$ 541.7 billion came for agriculture, divided between crops (R$355 billion) and livestock (R$200 billion) products. With exports of around US$86 billion in 2016, the sector has significant relevance for Brazil: it accounts for almost 50% the country's total exports. The country is the world leader in exports of sugar, coffee, orange juice, and beef, the second largest exporter of soybeans and poultry, as well as the world's fourth largest exporter of pork. As the destination of 25% of Brazil's agricultural exports, China has become the county's main partner. However, these exports are virtually restricted to unprocessed or semi-processed commodities. Exports of highly processed or packaged food products are of little relevance and the processing industry caters primarily to the domestic market.

The recent evolution of agricultural commodities varies considerably among the different segments. Before being hit by the global crisis of 2008, the sugar and alcohol industry was in full bloom, with a wave of new investments that would ensure it the lead in the emerging global ethanol market and in the advance towards bioeconomics. The crisis, however, led many companies to shut down their operations, while the lack of resources to renovate sugarcane fields decreased productivity. This scenario was further weakened by unfavorable ethanol prices, a prolonged drought, and the specific crises experienced by two important investors in the sector - Petrobras and Odebrecht.

With regard to animal proteins, since the early 2000s some domestic companies have grown through mergers and acquisitions. This process has significantly reduced clandestine slaughtering and opened up space for planted pastures and semi-confinement. The adoption of quality control, tracking, and georeferencing techniques as well as of organized management systems and genetic improvement techniques are gradually leaving extensive livestock farming behind.

Coffee, which has historically led Brazil's agricultural exports, has been severely affected by quality products from Colombia and other countries, as well as by cheap coffee from Vietnam. Stimulated by the new demand for specialty coffees in Europe and by the emergence of the coffee shop culture in Brazil, the sector has been shifting towards the quality that led exports to win over the demanding Japanese market as well. At the same time, productivity more than doubled due to changes in the production process and to harvest mechanization.

Currently, the leading agricultural commodity is soybean. Soybean production has run parallel to that of corn, which is grown immediately after the soybean harvest and has also become an important export commodity. Soybean producers have already incorporated the no-tillage model by using herbicide-resistant transgenic varieties, thus simplifying the production process and encouraging greater scales. In turn, investments in equipment have enabled producers to adjust to these new scales. Notwithstanding important advances in productivity, this growth has been made possible by the expansion of planted areas - first in the Cerrado and then in the country's Northeast and North regions. In 1990, Brazil grew less than 10 million hectares of soybeans, but in 2016 that number had already increased to 33 million hectares, with a production of 114 million tons. Of these, 52 million tons were grain exports: 62% to China and 14% to other Asian countries. Almost half, however, was destined for domestic consumption, thus evidencing the importance of domestic demand. The soybean planted area is expected to exceed 10 million hectares over the next decade.

5.3 What are the relevant technologies and their potential impacts?

As shown in Graph 12 below, to a large extent the transformations stemming from the various technology clusters do not cause short-term disruptive impacts on producers of intermediate inputs.

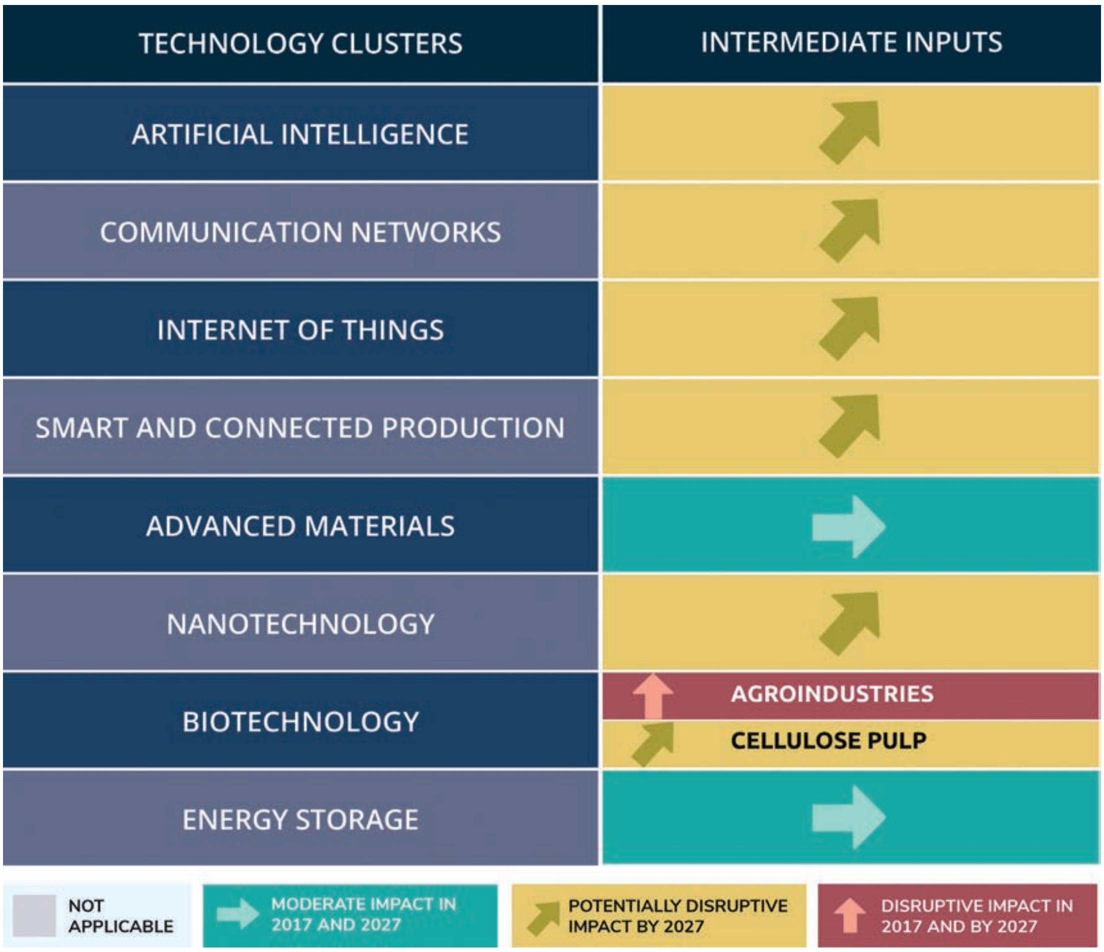
For all producers of intermediate inputs, from the exploitation to the processing of raw materials, relevant technologies are those associated with process control, such as sensors, big data, AI, and communication networks, whether or not embedded in capital goods or supplied by digital service providers. Moreover, for agroindustries and cellulose pulp, biotechnologies and new materials enhanced by integrated use with digital technologies are essential, as is the case in pharmaceutics and bioeconomics.

These are process and organizational innovations, many of them in a mature stage, such as communication networks. However, even in the communications sector, innovations (5G networks, for example) that are still in the selection process as regards dominant patterns are expected to emerge. Innovations in intermediate inputs are generated by producers of ICT, capital goods, and chemical inputs, or even by biotechnology companies in strong interaction with users.

Since continuous processes, in which technical progress moves slowly, prevail in the production of intermediary inputs, a few ruptures can be expected by 2027, as a result of the diffusion of new technologies. These should reinforce existing trajectories and entail continuous improvements in both processes and products. In particular, digital technologies are appropriate for continuous processes since they optimize physical-chemical transformation and conversion flows.

As these are generally scale-intensive activities, investment in new technologies is low in relation to total investment, while return rates can enhance competitive advantages in terms of cost and capacity to meet technical specifications, which are essential to these activities.

Graph 12 – Technology clusters relevant to intermediate inputs



Source: Prepared by the I2027 project team.

Programmable logic controllers, which record physical-chemical transformation parameters, have been present in these industries for a long time. Their use, however, tends to grow whilst their design moves towards reduction and autonomation. Sensors, for example, are being increasingly miniaturized by the development of temperature and pressure resistant nanotechnology, with improved batteries and integrated into an information transmission system. New generations of digital technologies can further extend the life of plants and equipment, often of very high unit value. They also introduce new functionalities, such as predictive maintenance and precise knowledge of the needs and challenges of their clients, and may even lead to a direct relationship between producers and end users, thus eliminating commercial intermediation links.

But changes will be disruptive for suppliers of technological solutions: producers of capital goods, chemical and biotechnological inputs, and ICT service providers. In the technical base of capital goods producers, the importance of metal and mechanical-based technologies declines while the importance of digital technologies and advanced materials grows. Some agricultural production segments and producers of chemical and biotechnological inputs will need to introduce genomic technologies with the potential to transform business models, competition patterns, and market structures.

Providers of ICT services transcend the generation and diffusion of technical information to provide specifications for how and when to plant or harvest with a high degree of precision. Agritechs or agtechs emerge as a new economic agent and the processes of survival, growth or absorption by other companies are still at an embryonic stage. Likewise, if in the early 1980s the then-new biotechnologies led the seed industry to be absorbed by the chemical industry, and today both the input and machinery industries are being restructured by big data management. Companies that did not traditionally operate in the industry, such as Google and IBM, are becoming directly involved in providing agricultural services.

When research grows in importance for the generation of new products and processes - as is the case of synthetic biology in convergence with digital technologies - ecosystems, especially those oriented towards innovation, become relevant for agribusiness. Large consortia of public and private institutions are being set up in the U.S. and in Europe to organize genomic sequencing, on a global scale, of all life on earth, including microbiota-related plants and animals. The goal is to unveil the evolutionary process as much as possible and understand how organisms have adapted to different ecosystems throughout evolution. These are big data initiatives in genomics, with unprecedented repercussions for science in general and for biotechnology in particular. One of such initiatives, with estimated costs of US$4 billion, is the Earth Biogenome Project (EBP), which seeks to sequence two million species of eukaryotes representing the five megadiverse biomes on the planet. Brazil, through the Research Support Foundation of the State of São Paulo (FAPESP), is already taking the first steps to participate in the EBP.

Agribusiness ecosystems in Brazil are very unique. They can be fully private, like when chemical-based companies partner with digital companies and/or equipment producers; and they can also be led by the public sector through direct interaction with users, as is the case of the Brazilian Agricultural Research Corporation (EMBRAPA). They can also be organized into public-private partnerships, such as the Sugarcane Technology Center (CTC), a company dedicated to R&D in sugarcane varieties, whose partners are private companies and the National Bank for Economic and Social Development (BNDES). There are many ecosystem configurations in the agribusiness production system, which gives it sufficient flexibility to address and propose different solutions for the industry.

Even if technical progress is slow in intermediate industries, digital technologies have the potential to induce integrated, connected and smart production that "pushes" levels of efficiency, quality, flexibility, and safety. This type of production streamlines the management of both the business unit and production through the collection and transmission of data to specialized analysis centers equipped with hardware and software capable of capturing, processing and, in the direction of artificial intelligence, providing solutions in real time or in advance. This enables advances in preventive maintenance that allow operators to detect signs of problems and act before processes collapse. In addition, robotics, including autonomous robotics and drones have become important in routine inspections of isolated operational areas.

The usefulness of digital technologies for process industries is unquestionable, given the complexity of managing large amounts of processes in large physical spaces. In contrast, the amount of data and information to be addressed requires changes in both management practices and people training. Because these solutions are provided by companies outside these industries, their implementation is available to all companies within an industry. The willingness to invest and the type of each company's decisions with respect to digital technologies are therefore of strategic importance in the competitive process.

Besides these common trajectories among producers of intermediate goods, in two links of agribusiness production chains - agricultural production and distribution logistics - some digital technologies emerge in a specific way while others, mainly of biotechnological nature, emerge with relevance.

The phrase that synthesizes the orientation of technological change is "precision agriculture". Similar to the process underway in the pharmaceutical industry, which is characterized by the search for medicines that match the patient's profile, in the agricultural sector biochemical equipment, information, and solutions must be capable of distinguishing and acting on very limited physical areas. The use of sensors and drones to monitor soil and crop conditions ensures greater selectivity in the use of water and pesticides. In large-scale agricultural production, the tractor becomes a mandatory gateway for both chemical and genetic inputs. There are prototypes of autonomous tractors and harvesters, but the current ones are already connected, generating and receiving information. Another trajectory is the replacement of large tractors with smaller units to mitigate problems arising from soil compaction. These are integrated, convergent, connected, and increasingly smart innovations that imply process and organizational changes in both agribusiness and ecosystems. These solutions are at different stages of development: some are mature while others are still in rapid development, as is the case of synthetic biology, but all of them open up spaces for greater product quality and development of new products that virtually replace the existing ones.

The process of generation and diffusion of integrated, connected, and smart technologies is resulting in surprising business movements: leading companies in the seed and chemical input sectors have understood this shift of economic power to the control of information systems over the use of inputs, whose gateway is the tractor, and have entered into cooperation agreements with equipment producers. At the same time, each company is extending its activities to different segments of the digitized world. For example, Monsanto purchased Precision Planting and The Climate Corporation - both developers of farm management information systems - in 2002 and 2003 respectively. Equipment companies such as Deere, CNH and AGCO are acquiring drone companies. Even in the case of products that pose a direct threat to their core products, leaders do not ignore the potential of new businesses. There are already more than a dozen startups developing meat alternatives either from vegetables or through tissue culture and fermentation techniques. Tyson, a global leader in all types of meat, has bought a stake in the Beyond Meat startup, whose vegetable-based product, The Beyond Burger, is already being sold in 11,000 U.S. outlets. Cargill, in turn, has acquired Memphis Meat, a company that synthetizes meat strips from stem cells.

These examples show that included in a big data and AI package, biotechnologies are now experiencing important advances in agribusiness, as is the case of CRISPR technology, which is capable of manipulating individual genes when designing and standardizing biological components - or even entire biological structures - to change the way organisms function. As for the agronomic area, in addition to the production of microbials, its goals are to increase resistance to water and thermal stress conditions and change the photosynthesis route to accelerate growth and promote nitrogen fixation. Synthetic biology is transforming fermentation technologies, which are essential for advancing the biorefinery model and were developed for biofuels and bulk chemicals. Petrochemical, agrochemical, and forestry companies as well as traders are investing in the area, while new fermentation techniques enable reproducing natural flavors, fragrances and oils, in direct competition with agriculture. For example, ADM works with Ginko Bioworks in the production of ingredients, and Cargill has recently launched a stevia sweetener based on this technology, in partnership with Evolva.

Digital technologies also optimize the efficiency and quality parameters of the management of logistics and distribution chains, which are essential for activities that mobilize long-distance transport of high production volumes. The processes of introduction and diffusion of the use of big data and artificial intelligence in these activities is facilitated by the actual or potential availability - but easily to be compiled - of the information necessary for setting up and handling large databases. Traders face several problems related to supply chain management, for which integrated digitization strategies are more challenging but are already beginning to transform business and coordination models. All leading companies are developing systems to digitize their business operations. For example, in 2015 Bunge adopted Cargo Docs to eliminate all paper documents and plans to introduce electronic bills of lading and presentations in all grain and oilseed operations; ADM adopted the Tradeshift platform and Luis Dreyfus developed Demeter International Trading, an in-house platform that has already been implemented in Argentina and is slated to be extended to other operations.

High volumes of public high-precision information captured by long-range sensing equipment like satellites, as well as information collected from private properties are available in primary activities such as agriculture. The wide availability of public information and the collection, analysis and supply of this information as services provide benchmarks for agribusiness, as well as indications of possible production improvements. At the same time, the use of information collected from producers leads to debates, which are still open, about data privacy. Different big data appropriation strategies encourage this debate, which will require, at some point in the near future, a minimum of regulation that enables reconciling different interests. In addition, other factors constrain the speed of adoption of these technologies, such as the age of producers, costs, and infrastructure limitations. However, efficiency gains are relevant. Big data software and the prospect of a free-fall in the prices of drones and sensors enable combining ever-increasing production scales with control and full knowledge of the terrain - once seen as advantages of small production alone. In the medium term, remote-controlled agriculture, in which the physical presence of technicians would be rare, should be made possible by the diffusion of IoT.

5.4 Where are we now and where are we headed? Relevant technologies in companies

Most Brazilian producers of intermediate goods are not yet advanced-technology intensive, especially as regards digital technologies. However, there are signs that diffusion will reach a moderate level in 2022 and a high level in 2027. Regarding specific sectors, in 2027 the use of advanced technologies is expected to be high in the aluminum, cement, mining, and cellulose pulp industries and moderate in the steel industry. Despite their still initial position on a maturity scale (awareness of the importance of using advanced technologies), companies are closely following what is being done in other countries, are concerned about the widening of the technology gap and understand what it takes to accelerate national efforts. This trajectory of Brazilian companies was highlighted in the chapter that analyzed the digitization of Brazilian industry and is in line with international benchmarks. In this environment, however, some companies already have proactive strategies and are using frontier solutions.

Because these activities are process- and capital-intensive, it should not be difficult and costly for companies to undertake digital modernization efforts. For companies with older plants, as is the case of several oil refineries, these solutions could extend the life of the equipment, thus enhancing operational efficiency. For plants that have been modernized, as is the case of some cellulose pulp companies, digital solutions are already incorporated into the equipment.

Even if these innovations are incremental and "optimizing" in the sense that they will not cause disruptions in key competitiveness factors and market structures, management challenges are not less pressing. Companies that have implemented advanced technologies had to be attentive to and implement significant change processes in the way they organize tasks, in their workers' profile and in their relations with suppliers.

The common lessons of the most advanced companies are relevant. All of them are based on the existence of a great amount of data, little organized information and rare analyzes encouraging pro-efficiency, quality, and safety measures. Likewise, for digital modernization to be implemented, decisions must necessarily be made at the highest corporate level, and top executives need to be directly involved in planning, implementing and monitoring results. Changes in the form of internal communication (via smartphones, for example) and the use of equipment with sensors to ensure safety procedures in the workplace lead to changes in the routine of workers, who had to be trained in the use of digital technologies. The fact that the supply of courses was not always available required strong interactions with vocational training institutions such as SENAI, which were also just beginning efforts in these directions.

Changes in external relations are also important. Implementing product-tracking solutions (with the use of radio frequency locators, for example) required establishing new customer relations bases. Integration companies in the area of digital modernization are an important complement to help define patterns that may arise as a result of rearrangements in internal and external relations. In the chemical industry, for example, a tendency to be captured - perhaps more strongly in relation to specialties - is that the impacts of digital transformations go beyond operational efficiency gains. Digital technologies make it possible to improve the quality of product use. In addition, new services can be offered and, in some cases, product sales can be converted into service provision. The possible emergence of players capable of organizing, structuring and exploiting data suggests the entry of competitors, such as startups, that hitherto did not belong to the chemical industry production chain.

The case of Brazilian agritechs is emblematic. In several places in the country, agricultural startups are emerging and being subject to public and private promotion in the form of agrihubs, with the provision of infrastructure and support for the transition from the invention to the market stage. Noteworthy are the ecosystems of startups from Piracicaba and Mato Grosso. Hundreds of companies, most of them providers of information services to business based on online and offline applications, point out a serious problem in agriculture: lack of adequate access to communication networks. Large companies are also moving forward. Some examples point to increasing sophistication in the supply of advanced technologies for agribusiness. Totvs has the Carol robot, whose AI is available in the cloud and accessible through iOS or Android applications. This solution applies machine learning to data, learning about previous harvests to improve its recommendations. Company clients include large producers such as Bom Futuro, Amaggi, CGG, and Granbio. Technical cooperation between IBM and Agrotools makes AI possible from the Watson platform. The strategy is to offer differentiated services to each type of client. Monsanto - now Bayer - is exploring AI in partnership with Atomwise to assess potential applications of molecules in agriculture.

Other important transformations in agriculture include the adoption of crop-livestock-forestry agricultural integration systems promoted by EMBRAPA and encouraged by low-carbon credit policies arising from commitments made by Brazil in international climate change agreements. It is estimated that 11.5 million hectares in the country are already using variations of this system. A major advantage of the model is its alignment to the main strategy in the grain sector: agroindustrial verticalization and transition from export to industrial processing of meats and other products. On the other hand, the system is very demanding in terms of management and runs up against the lack of skilled labor - a central problem in the transition to precision agriculture in the country.

Among producers of intermediate goods, agricultural commodities boast greater advances towards the generation, use and diffusion of advanced technologies. Brazilian companies have already affirmed their international competitiveness in a wide range of products - soybeans, corn, sugar, orange juice, coffee, cellulose pulp, tobacco, and meat. Upstream and immediately downstream industries - all world leaders – are already using and promoting digital and genetic technologies, and large agricultural producers are already using embedded digitization equipment and genetic biotechnology inputs for agriculture, although still on an experimental basis.

Companies are moving forward, but they are also facing challenges. The diffusion of advanced technologies depends on the existence of a new generation of technicians with a very different set of skills and experienced in and knowledgeable about new technologies and management tools. Large producers have Internet access on their farms and express interest in incorporating big data analytics. However, there is no access to high capacity and speed networks, which are essential for the incorporation and diffusion of IoT. The positive and rapid response of large producers suggests that digitization will offer significant increases in cost and productivity efficiency, due to its capacity to manage large undertakings with the meticulous control that is typical of small production. In this context, the dissemination by EMBRAPA of a crop-livestock-forestry integration model as the most sustainable in the Cerrado may face great obstacles.

For small-scale agriculture, the projection of an exponential fall in prices suggests that access to technology perhaps is not an insurmountable obstacle. However, social movements and many associations that promote small-scale or family agriculture are suspicious of advanced technologies. On the other hand, there are many experiences in the promotion of digitized crops through open innovation systems adapted to local ecosystems and to the need to preserve the producers' privacy. There is already an important group of fully technified producers; the major problem does not seem to be access to technologies, but the new skills required of farmers. This shortage requires extension and technical assistance programs that are different from the traditional programs of the past: the emphasis shifts to management, technological solutions, development of partnerships to implement them, and financing channels suitable for this new scenario.

One of the highlights of agroindustries is the production of grains in the Cerrado region. Growing local voices point out the need to redirect the agricultural model in the Cerrado, which in its current form may fail to generate inclusive local and regional development conditions. The extent to which the digitization process in rural areas generates new complementary jobs does not seem to be clear. However, the most important is the environmental questioning about the impacts of grain agriculture on the Cerrado biodiversity. From this perspective, sustainability can become an organizing vector of the incorporation of digitization in agriculture. Companies in the segment have proven competence and depend on an international market that is increasingly demanding from the environmental point of view, and are therefore capable to improve their sources of sustainable competitiveness in partnership with research centers. The biggest risk to the absorption of this technology, however, is that its efficiency gains in cost and productivity will deepen the current model instead of moving towards sustainable practices and strategies for job creation and the development of local/regional dynamics.

The Brazilian cellulose pulp industry was a world pioneer not only in the introduction of a new input, eucalyptus, but also in the generation of innovations for the uniform and rapid growth of trees, thus reducing capital rotation time and the use of agrochemicals. Advances in biotechnology have allowed for the development of genetically modified eucalyptus: the first commercial use of a eucalyptus of this type was approved by the National Technical Biosafety Commission (CTNBio) in April 2015 for Suzano's Futuragene company and enables reducing maturity time from 7 to 5.5 years. Biotechnology is also present in the processes: enzymes are being developed to replace chemical inputs in order to extract "clean" pulp, thereby reducing CO_2 emissions, promoting savings in water treatment and increasing biofuel production capacity.

In the steel industry, partial changes may occur in business models as a result of the opportunities afforded by the progress made in advanced materials, which are also connected to innovations in nanotechnology and energy storage: the advance of composites increases competition with substitutes, entailing improvement in the product mix, such as the development of alloys and intermetallic compounds and nanostructured magnetic materials.

In the case of aluminum, lighter and stronger alloys are expected to be developed. In this and in the cement sector, the change in the business model will be driven by the consolidation of the trend towards multi-material companies. In the cellulose pulp industry, there are many opportunities for the application of nanostructured materials such as nanocellulose, both in the internal dimension - in the scope of products in the current portfolio - and in the external dimension - in the form of innovative products that complement the current production line.

It is in mining, however, that the development and diffusion of advanced materials gain prominence and have the potential to boost new industries. These materials have the capacity to reduce the weight and volume of products, customize them to the needs of each equipment, improve desired features, increase their useful life, and reduce material and energy consumption. The new alloys bring great benefits to consumer sectors by reducing energy consumption, greenhouse gas emissions and noise, and by increasing safety and durability. Also worth mentioning is the potential of Brazilian high-quality quartz reserves for the production of photovoltaic cells. By 2027, research is expected to be more mature and technology more widespread. These studies include nanostructured magnesium-based alloys and titanium and chromium compounds capable of storing high amounts of hydrogen. The same applies to electronic structures of carbon nitride nanotubes and resistant silicone microstructures.

5.5 Our challenges, risks, and opportunities

According to producers of intermediate inputs, the main challenges in moving forward are related to market and investment cycles. In the case of the steel industry, for example, the context is one of structural imbalance between installed capacity and demand. In the case of cellulose pulp, despite the low level of idleness and the recent increase in international prices, the investment discipline is cause for concern. As for agricultural commodities, major exporters are more willing to invest due to growing international demand.

For most producers of intermediate goods, new technologies will not entail transformations in business models. In this sense, these technologies are functional to legacy systems and to existing machines, which have a long lifecycle. This results mainly in increased efficiency, quality and safety, and reduced emissions. In the same direction, online monitoring of equipment behavior enables intervening in a programmed manner by anticipating failures and increasing the availability and reliability of production parks.

Therefore, the strong tendency is for producers of intermediate inputs to follow the best international production and technological practices. This trajectory is feasible for companies upstream production chains for two complementary reasons: (i) their markets, especially international markets, are growing and the prices of their products are attractive; and (ii) that is where large, high production scale companies are located (including in the case of agriculture).

This means that investments in new technologies are a competitive necessity and relatively small compared to a greenfield investment. The lessons from companies that are already implementing digital modernization are relevant: the direct involvement of top management and attention to changes in internal work routines and in external relations are necessary conditions for the success of endeavors in this direction. With the involvement of business leaders, large producers of intermediate inputs should keep up with technical progress worldwide, with the support of their productive and innovative ecosystems.

In some market niches, such as family agriculture and downstream supply chains, the challenges are of a distinct nature: medium and small enterprises tend to lag behind technology-wise, their markets cannot pressure for technological upgrading, investment in new technologies may be significant for the resources available in the companies, and their entrepreneurs may not yet be informed of the transformation potential that these technologies can bring. Paths to be trodden to meet existing challenges facing small producers can include expanding and renewing extension initiatives to incorporate technology and innovation management, as well as financing under special conditions, in exchange for the adoption of new technologies and environmental sustainability.

In some ecosystems the situation is the opposite: Brazilian industry can compete for the international frontier. In cellulose pulp, companies are making efforts in advanced biotechnology either in their R&D departments or in investments in technology-based companies located in Brazil and abroad, and in cooperation with public research institutes such as EMBRAPA Agroenergia. They are also endeavoring to push the international frontier of efficiency and environmental sustainability, as well as to open up new markets. This transformation is symbolized by the name of their association – "Brazilian Tree Industry". The cellulose pulp ecosystem is therefore structured from business initiatives, in partnership with the public sector.

In agribusiness ecosystems, there is a great variety of participants and configurations. The EMBRAPA system, with more than 2,400 doctors, is an international reference of quality and innovation capacity. Other relevant players are federal and state research institutes such as the Research Center for Energy and Materials (CNPEM); leading international companies; suppliers of seeds and chemical inputs that rely on research bases in the country; and the research centers of domestic and foreign equipment manufacturers that develop innovative solutions worldwide. The emergence of hundreds of digital services and technology-based agritechs is changing relations between the links of production chains. Agricultural product traders are introducing digital solutions for logistics management.

Brazil is one of the five megadiverse hotspots on the planet, with hundreds of thousands of plant and animal species and millions of species of microorganisms inhabiting areas with nutrient-poor soil and serious water restrictions. Interestingly, the diversity of plant and animal species is greater in these dry environments with poor soils. Most likely, the microbial diversity of these environments interacts with the plants, thus favoring both the acquisition of nutrients and defense against pathogens. The genomics of Brazilian biodiversity, including plants, animals and microbiota, is almost totally unknown and therefore represents a huge opportunity for national biotechnology. However, advancing in this area requires renewing the country's research base. The challenge is to implement, from the existing scientific basis, R&D pipelines capable of positioning the country in the global market for advanced agricultural biotechnology. Pipelines operating in organized processes involve multidisciplinary teams with expertise in molecular biology, genomics, bioinformatics, and ecophysiology, among other disciplines, to identify potential target genes and their regulatory sequences.

The Earth Biogenome Project (EBP) provides opportunities to explore sources of genomic information that can be directly used through genomic editing, for the allelic reconstruction of large crops, leading to the development of more efficient varieties in terms of nutrient acquisition, higher photosynthetic efficiency, more effective use of water and, above all, greater tolerance to diseases and pests. In turn, sequencing the genomes of microbial communities inhabiting the different organs of plants and animals should create opportunities for the development of new products and processes related to both plant defense against pathogens and animal health. Brazil has expertise in terms of quantity and quality to make a meaningful entrance into this new era of biotechnology. Genomic sequencing centers, such as those at Unicamp and USP, can quickly increase data generation capacity at a low cost and support the country's need to participate in large global consortia. Brazilian bioinformatics has already shown its strength by implementing the FAPESP genome program, and can be quickly regrouped. However, participation in global consortia such as EBP cannot be limited exclusively to the research groups of academic institutions. It is essential to create mechanisms for private sector participation with direct investments. The creation of startups focused specifically on exploring the information generated by EBP is an alternative to leverage industrial applications of advanced biotechnology.

6

CONSUMER GOODS: REDUCING DISTANCES TO THE PRODUCTION FRONTIER TO INCREASE PRODUCTIVITY

6.1 Who are the producers of consumer goods?

This set of economic activities encompasses producers of a wide variety of industrial goods, including durables such as automobiles and home appliances, and non-durables such as processed food products, beverages, toiletries, and apparel and footwear. The sectoral foci selected were Light Vehicles (from the Automotive production system); Home appliances, Textiles, Apparel and Footwear (from the Consumer Goods production system); and Processed Food Products (from the Agroindustry production system).

The manufacturing processes of these goods have different features. The production of durable goods such as home appliances and automobiles involves successive stages of manufacturing and subsequent assembly of parts and components on a large scale, with a high degree of automation and intensive use of equipment. In the group of non-durables, the design and production of footwear are also manufacturing processes, but less automated and more labor-intensive. In turn, processed food products and fabrics are produced in almost continuous automation-, scale- and equipment-intensive processes.

Despite these differences, there are common technological and competitive features that bring producers of consumer goods together. First, the dynamics of innovation is focused on creating new markets, by either launching new products or revamping existing ones. Innovating products by replacing existing ones or incorporating new features or a new design is the main vector of competition. Product differentiation based on its functionalities, design, packaging, brand, and advertising, among other variables, is typical of producers of automobiles, home appliances, processed food products, apparel, and footwear.

The periodic launch of new models in large marketing events, once restricted to clothing and footwear collections, is now widespread among producers of consumer goods. Market segmentation based on the lifestyle and income level of consumer groups is also an essential part of business strategies in these industries. Product innovations incorporate new materials or components developed by suppliers, but the accumulated knowledge about the profile of target consumers and distribution channels is held by the manufacturers of final goods.

Secondly, manufacturers of consumer goods are to a large extent beneficiaries of process innovations developed by their input, equipment and service suppliers. In some cases, these are specialized suppliers such as manufacturers of machines for the textile industry, the apparel industry or the processed food industry. In others cases, these are manufacturers of industrial equipment of general use, such as machine tools, robotic mechanical arms or assembly lines. In the case of services, these may be both digital solution providers (management software) and providers of specialized technical or innovation services. Whether specialized or not, suppliers of knowledge-intensive inputs, equipment and services disseminate innovations in consumer goods industries.

Brazil has a large consumer market, with a strong presence of subsidiaries of global companies in both durable and non-durable goods. In some segments, such as the production of automobiles, home appliances and small appliances, the subsidiaries of global companies are responsible for almost the entire production of final goods and for a significant share of parts and components. In other segments, such as production of processed food products and fabrics, there are large domestic companies with international operations. Small nationally-owned companies have a significant presence in the apparel and footwear industries as well as in some home appliance niches.

In addition to the diversity of durable and non-durable products offered, in Brazil a striking feature of these industries is strong heterogeneity in terms of technological capabilities and competitiveness among companies from various segments. However, some considerations are in order. In the durable goods industries, when quality is defined in terms of suitability for use, the quality of products is on a par with international references. In terms of technological sophistication of products, however, a significant proportion of the goods offered to the Brazilian market does not keep up with the international frontier, and local demand – which is not significant volume-wise - is met by imports. The supply chain, however, has specific features in different segments of durable goods. While in the automobile industry first-tier suppliers and automakers have equivalent capacities, heterogeneity grows along the chains, in parallel to the greater participation of smaller companies.

With regard to textile-apparel-footwear industries, larger companies with technical and competitive capabilities are at the base of the textile chain. In the apparel and footwear segments, capabilities and performance vary according to the company size (special mention should be made of smaller companies operating in high unit value niches that are international trend-setters). In the industry of processed food products, differences between companies are also related to size, but larger companies, as opposed to their international counterparts, still fail to strongly incorporate the healthfulness agenda.

6.2 What is the economic importance of consumer goods and what are the determinants of innovation and technological change?

Three changes are accelerating and transforming the profile of world production of and demand for consumer goods and services:

- The first change refers to the rapid industrialization and urbanization processes of Asian countries, especially China, that shift production and enable the entry of new competitors. The rise of the so-called "emerging middle class" in the Asian region but also in Latin America meant the incorporation of hundreds of millions of people into the world consumption map.
- The second is the increasing diffusion of means of communication, which globally and instantly disseminate images and messages that fuel the wishes of consumers.
- The third set of changes stems from the higher level of per capita income, which makes access to a wide variety of goods virtually universal and consequently enhances product differentiation as an important vector of consumer market expansion.

Consumer goods make up the bulk of the world's supply of final goods, and their production has increased significantly in quantity and variety. Asian countries concentrate both production and the relevant share of demand.

Changes in the consumption profile occurred concurrently with the transition to a new international trade and investment system promoted by the conclusion of the Uruguay Round in the mid-1990s. The greater permeability of domestic markets to the movement of goods and capital promoted transformations in the world production and consumption map - a process in which the consumer goods production system played an important role.

Suppliers of consumer goods have adjusted their strategies to this evolution, with important impacts on market structures and dominant competition patterns. Both durable and non-durable goods are undergoing a strong process of internationalization of their production and distribution networks. Producers of consumer goods have embraced global value chains as a typical way of organizing their business in the world. Thus, the key players control an extensive and complex network of suppliers, producers and distributors worldwide.

Naturally, global chains in the consumer goods production system operate differently. In the segment of non-durable consumables such as textiles, apparel and footwear, the value chain is controlled by companies specialized in the management of brands and marketing systems, or even by retail chain owners. In turn, production of durable goods such as home appliances and automobiles are led by industrial companies.

Value chains link suppliers of different profiles, located in several countries and under constant pressure to reduce costs and defend profit margins in a context of accelerated innovation and reduced product lifecycle. The competition for value generation and capture within global chains is fierce.

The automotive complex is one of the most powerful and influential industries in the world. The automotive industry employs 5% of all manufacturing sectors, which represents approximately nine million direct jobs worldwide. For each job directly created by an automaker, another five indirect jobs are estimated to be created in other industry-related sectors such as steel, plastics, textiles, glass, etc. In 2016, approximately 95 million vehicles were produced, a 46% increased against 2006. Still in 2016, China led the world production of vehicles, followed by the United States, Japan, and Germany. In that same year, Brazil ranked tenth in the world, with just over two million vehicles. In 2015 the top ten automakers accounted for 70% of all vehicles produced.

In the Brazilian automotive system, the light vehicle segment is responsible for much of the production and for the dynamics of the system itself. Investments by foreign automakers in the country have run parallel to the entry of international suppliers of auto parts, as a result of strategies of global platforms, with the definition of global player suppliers that should preferably follow the automaker wherever it carries out production. In the period 2005-2012, the Brazilian automotive system experienced a remarkable expansion in terms of sales, becoming one of the great world markets for light vehicles, although still far from large Asian markets.

Asia is the global leading manufacturer of consumer goods, accounting for about two-thirds of the world's production of textiles and apparel and about 80% of footwear production. This concentration is justified by both the booming consumer market and its advantages in terms of labor and logistics costs. The participation of developed countries is concentrated in more technology-intensive and high value-added activities.

Most of the output of the consumer goods production system in Brazil comes from subsidiaries of foreign companies in the segment of durable consumer goods and large nationally-owned companies - with international presence - in the apparel and footwear industry. The latter also includes smaller companies, generally with low production capabilities. Another feature of the Brazilian system is that production is mostly destined for the domestic market. In this context of a large domestic market and a sophisticated and heterogeneous industrial base, the Brazilian consumer goods production system is a unique relatively autonomous and differentiated case in relation to global value chains.

The food and beverages industry stands out in the manufacturing sector, with a share of 10% to 30% of the industrial product, depending on the country. Globally, it generates revenues of around US$4 trillion and employs 25 million people. Production and innovation are concentrated in industrialized countries, but market growth is shifting to emerging countries, where companies on the way to becoming global players are also emerging.

In Brazil, there is a clear bifurcation: on one side are internationally competitive agribusinesses in the primary production of a wide range of commodity chains. On the other side is the food industry, which produces mainly for the domestic market, with limited export capacity despite the leadership of global companies. Sales by the processing industry, including semi-processed food products, are estimated to have reached US$225 billion in 2015; of this amount, US$41.3 billion was exported and US$173.8 billion was consumed domestically, with US$117.7 in retail and US$25.5 billion in foodservices. The domestic market is the seventh largest in the world and essentially self-sufficient, with the important exception of wheat and, to a lesser extent, dairy products. The growth of the food production sector is subject to Brazil's socioeconomic characteristics. The enormous potential of the internal market is under-utilized due to income inequalities. Brazilian families spend on average 7.5% of their income on food. In lower socioeconomic groups, the percentage is 32.7% - four times the percentage of higher income groups. Brazilian exports of primary and secondary processed food products grow slowly *vis-à-vis* the commodities segment and international competitors.

6.3 What are the relevant technologies and their potential impacts?

The technologies with the greatest potential impact are those that enable new products and new business models or radically change existing ones. Disruptive impacts of this type are observed in the automobile, processed food, home appliances, textile, and apparel industries.

There are also innovations that strongly impact manufacturing and integrated management processes in the value chain. The higher impacts occur in manufacturing processes with successive stages of parts production and assembly through automation, resulting in: (i) productive efficiency in terms of reduced losses; (ii) flexibility to enable the customization of products for specific market segments; and (iii) control of value chain management. Impacts of this type occur in the automotive, home appliances, apparel, and footwear industries. In textile and food and beverage production, the highest impacts occur in value chain management, since the processes are almost continuous and highly automated and the impact on them is relatively lower.

Graph 13 illustrates the intensity of the impacts of technology clusters on the different producers of consumer goods analyzed in this study. Innovations in each of them are already evident in all industries and the impact will grow over the next few years. Few innovations, particularly those related to energy storage, should not cause disruptive impacts on these systems and sectoral foci, with the exception of the automotive industry, in particular light vehicles, which is moving fast towards electric motorization. New biotechnologies (synthetic biology) are already transforming business models in some segments of the processed food industry, while advanced materials and nanotechnology are also affecting some producers in the textile industry.

Graph 13 – Relevant technology clusters: food, motor vehicles, home appliances, textiles, apparel, and footwear

	PROCESSED FOODS	AUTOMOTIVE	HOME APPLIANCES	TEXTILES, APPAREL AND FOOTWEAR
ARTIFICIAL INTELLIGENCE	↗	↗	↗	↗
COMMUNICATION NETWORKS	↗	↗	↗	↗
INTERNET OF THINGS	↗	→	↗	↗
SMART AND CONNECTED PRODUCTION	↗	↗	↗	↗
ADVANCED MATERIALS	→	↗	↗	↑
NANOTECHNOLOGY	↗	↗	↗	↑
BIOTECHNOLOGY	↑	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE
ENERGY STORAGE	→	↑	→	→

NOT APPLICABLE | → MODERATE IMPACT IN 2017 AND 2027 | ↗ POTENTIALLY DISRUPTIVE IMPACT BY 2027 | ↑ DISRUPTIVE IMPACT IN 2017 AND BY 2027

Source: Prepared by the I2027 project team.

6.3.1 Automobiles

All technology clusters impact the automotive production system to some degree. Advances in AI, IoT and Networks generate innovations in products and also in manufacturing processes (SCP). Developments in advanced materials, nanotechnology, and energy storage make product innovations possible.

Within up to ten years, disruptive impacts on the most important products will come from advances in AI, IoT, and network technologies. The technological development of these clusters will make room for product innovations that already have a visible impact on company strategies and market structure. The most relevant disruptive impact is the shift towards the electric motorization of vehicles in its various aspects – electric-only and hybrid models - as well as the increasing incorporation of information and communication technologies, which change perspectives of support for driving, leisure and services inside the vehicle. There is also the possibility - although more distant timewise and more uncertain in terms of the commercial development - of self-driving vehicles, that is, vehicles without drivers physically behind the wheel. To these ruptures one should add important changes in the way cars are used, with the increased use of carpooling and restrictions on the circulation of vehicles.

Manufacturing processes tend to follow the general evolution of the mechanical industry towards smart and connected production - such as automation, additive manufacturing (3D printing), use of big data and machine learning, networking, IoT. Although these are important advances, in general they are not yet disruptive changes as intense as electric motorization.

Currently, the presence of electric vehicles is still modest - even in countries that have adopted incentive policies and measures -, with a share of 1.1% of the world market. There are also issues related to consumer acceptance and the infrastructure required for the further inclusion of electric vehicles in the automotive market.

The main barriers to the diffusion of electric vehicles are related to the cost of these vehicles compared to total costs (maintenance, fuel, etc.) as well as to autonomy and recharge and service infrastructure. Consumer acceptance is also a barrier. In addition, there are uncertainties about the useful life of batteries, which have a limited number of charge cycles and lose capacity with increasing charging cycles. In terms of technology, the world's largest automakers are investing in R&D and new plants, including in partnerships with IT companies. The business model for electric vehicles will change the relationship between automakers and their supply chain, but the direction of this restructuring is still unclear.

Energy storage is the sector's biggest technological challenge, although the trajectory seems steady from the perspective of the share of electric models in the portfolio of new models of all automakers and increasing regulation by countries and cities, which are setting dates for banning the use of internal combustion vehicles.

6.3.2 Home Appliances

The evolution of technologies associated with changes in consumption patterns arising from the expansion of the middle class, population ageing, and the dissemination of new lifestyles should lead to profound changes in the consumer goods market in the coming years.

Technology clusters relevant to the consumer goods production system are: advanced materials, AI, SCP, communication networks, IoT, nanotechnology, and energy storage. Advanced materials technologies will have disruptive impacts by replacing metallic and plastic components, making room for the development of lighter and more resilient home and portable appliances. These are, therefore, product innovations with high added value and premium prices. AI technologies will have a strong impact, with opportunities ranging from the development of domestic robots to the incorporation of AI into traditional domestic equipment such as smart home appliances with voice recognition and natural language processing. This impact will be reflected in the creation of new consumer markets, in the emergence of new business models, in the questioning of established advantages associated with the ownership of commercialization and distribution assets, and in the transformation and creation of products. In addition, AI technologies should also impact the retail market, particularly virtual search systems, by identifying consumer buying and behavior patterns.

SCP will have impacts related to the following technologies: (i) digitization, by allowing for increased interaction capacity between machines, with data accumulation and learning by these machines, making virtualization and comprehensive management optimization possible; (ii) competitive intelligence aimed at consumers, distribution chain management, and retail; (iii) additive manufacturing; and (iv) product development using virtualization technologies, especially in the manufacture of custom products. Changes associated with these technologies are expected to have significant impacts on business productivity, in order to reduce lead time in product development and increase the capacity to meet specific and customized consumer demands.

Network technologies, coupled with IoT and remote sensing will enable monitoring the lifecycle of durable consumer goods, with positive effects on predictive maintenance and the incorporation of new attributes and functionalities for consumers through remote applications. In the segment of non-durable consumer goods, network technologies will enable the adoption of new uses and applications in sports and health areas - including with the incorporation of assistive technologies - in sensor-equipped clothing and footwear. In addition, network technologies coupled with AI, IoT and SCP will have transformative impacts on the system's production processes, which may be reflected in new business models that bring industry close to end consumers and in potential impacts across the entire production chain.

The main advances in the incorporation of IoT will be linked to the sensing and monitoring capacity of products. In the case of home appliances, these technologies will enable incorporating new attributes into consumer products and services.

Energy storage technologies will produce smaller impacts on this system compared to the automotive system, for example. However, the diffusion of smart, highly mobile domestic robots will require integrated solutions in terms of energy storage.

6.3.3 Textile, apparel, and footwear products

In the textile and apparel industry, the main trends are the transition from a production and operations system based on mass customization to product customization; concern with the efficiency of the manufacturing operation, which leads to the incorporation of low energy and water use systems; and elimination of various costs typical of the operation, such as those related to inventory of finished products, development of products several months in advance, and logistics and distribution.

Important product innovations are expected from the use of morphologically altered materials, with the incorporation of sensors and nanoparticles capable of conferring functional properties to fabrics - for example, nanocellulose and functional synthetic fabrics combined with biopolymers, as well as fabrics with capacity to block ultraviolet radiation and fungicidal and bactericidal activity and properties such as insect repellency, drug release, and self-cleaning.

There will also be impacts from nanotechnology involving the increasing incorporation of attributes and functionalities to products, with important effects on the sector's competitive pattern. It is worth mentioning that this segment is already an important user of nanotechnological solutions in technical fabrics, but its application can be extended to other products such as apparel and footwear. Energy storage technologies will have minor impacts with the increasing use of sensors in wearables. The main potentials of biotechnology are concentrated in future applications in bio-fabrics, bio-fibers and bio-clothing, over a longer time horizon.

SCP will have impacts, also in this case, related to management, manufacturing and distribution of digitization technologies. Changes associated with these technologies are likely to have significant impacts on company productivity, in order to reduce lead time in product development and increase the capacity to meet specific and customized consumer demands.

In retail, these technologies also make it possible to eliminate the costs of prototype development and minimal production thus increasing flexibility for companies, enabling the production of high value and small volume items as well as multichannel retail. In addition, AI technologies should also impact the retail market, particularly in online search systems, thus allowing for the diffusion of personalized purchase recommendations and the emergence of custom apparel purchasing systems.

6.3.4 Processed Food Products

The challenge for the food industry is to develop products without ingredients and additives and/or the substitution of inputs such as sugar, oil, salt or even products that go through several processing stages. The current trajectory points to the incorporation of ingredients and biological inputs that allow for pro-health solutions. Relevant innovations may emerge from new biotechnology. The application of new biotechnology to food manufacturing is defined as the use of living cells - or part of them - to produce or modify food and food ingredients. For example, synthetic biology is transforming fermentation technologies that make it possible to reproduce natural flavors, fragrances and oils, in direct competition with agriculture. The same applies to the search for alternatives to traditional ingredients and additives like sugar, salt, and trans fats.

Genetic advances are being increasingly integrated with high-performance computing, big data and AI, making room for gene-editing techniques (CRISPR/Cas9) that increase the possibilities to identify and control the expression of genetic characteristics without involving interspecies transfers. As with pharmaceuticals, this combination increases the speed and decreases the time to generate new products. These low-cost techniques that face no entry or regulation barriers have been developed at the university level and to date have not been subject to exclusionary ownership by leading companies.

Many biotechnology applications to the food industry are generated by support industries and services. For example, the production of ingredients such as enzymes often depends on chemical companies, and processing innovation is related to engineering consultancies. Food packaging companies also adopt biotechnology processes to produce packaging containing information on the perishability of the food item. At the same time, food and beverage companies are increasingly investing in synthetic biology, due to the strategic role that this knowledge base acquires. Large companies diversify their research centers towards new biotechnologies or join and even acquire specialized technology-based companies. Cargill, for example, has acquired Memphis Meat, a company that intends to produce animal protein from cell reproduction technologies.

The adoption of digital technologies gives flexibility to the firm and contributes to achieving higher quality products that increase its competitiveness. Product traceability, essential to ensuring food safety and increasing the reliability of producers, is only possible through the adoption of digital technologies connected throughout the chain. For example, efficient and high-performance communication networks are essential for effective coordination between agricultural, food, retail and even consumer companies.

Because technological solutions are generated by specialized suppliers, innovative food companies rely on investment in inputs such as machinery, software and equipment. As differentiation is the key competitiveness factor in this industry, the adoption of digital technologies is associated with improved product quality, which can also enable reorganizing relations with suppliers and clients and introducing organizational change. The same applies to the use of IoT. At the factory level, IoT can help reduce maintenance costs by detecting problems before they occur.

The smart kitchen system is another IoT application that makes it possible to inventory food items stored at home, take diet control measures, prepare food remotely, and check the best before or expiry date of products, thus helping consumers to assess a product's safety before consuming it. Virtual supply chains using IoT are an enhancement of food traceability systems. In them, numerous industries and services can converge to generate the technology and put the system into operation: the food industry, the wholesale and retail sectors, the service sector - including banks, insurance companies and public authorities –, ICT industries, cloud operators, and software services.

6.4 Where are we now and where are we headed? Relevant technologies in companies

Contrary to what happens in continuous process industries, which are capital-intensive, in most consumer goods production systems, investment in new technologies accounts for almost the totality of investments in new facilities. This means that these new technologies will only be diffused on a large scale when a wave of investments in new production capacity occurs. Leading companies and associations of consumer goods industries in Brazil are aware of the depth of the potential transformations of new technologies in their sectors. However, the high heterogeneity of Brazilian producers should influence the development and adoption process of new technologies. The difference in terms of competitive capacity within the same industry can be largely defined by the size of the companies: larger companies have a higher competitive capacity and smaller ones have a lower competitive capacity.

The dissemination of product, process, and business model innovations tends to be uneven and will initially impact manufacturers targeting high-income consumers and specialized market niches, such as luxury automobiles, sophisticated home appliances, functional food products, or wearables in the sports clothes and footwear segments. In mass consumer market segments and for smaller producers, the diffusion of new technologies should take longer and be limited. In these segments, demand is less challenging and companies have fewer resources (financial and human) to cope with associated investments. Facilities, products and business models of different generations would be likely to coexist. This trend is enhanced by the income distribution profile of the population that allows for the coexistence of very different lifestyles and consumption patterns.

Regarding the Brazilian market for durable consumer goods, in the medium term a large group of high-income consumers should make room for the local production of smart and connected home appliances and hybrid vehicles (which, however, can be initially imported). In the long term, universal consumption of these goods will only be made possible through price reductions or the emergence of new business models that associate them with the provision of services. Manufacturers - almost all of them subsidiaries of global companies - should progressively upgrade their facilities by incorporating smart equipment, initially in isolated operational segments and progressively connected and integrated into networks, on their way to smart and connected production, following the trajectory of their respective parent companies.

The effective impact of new technologies on the production of durable goods in Brazil will depend on the strategies of final goods producers in relation to new products and on the capacity of local parts and component suppliers to increase their production by incorporating new manufacturing processes. The fragile link in the production of durable goods is the supply of parts and components, in which the demand is met by imports or by smaller companies. Radical innovations in final products and in new manufacturing processes can further weaken local parts and component suppliers and replace local supplies with imports. The activism of subsidiaries of foreign final goods manufacturers in the development of new smart and connected consumer goods and their effective engagement in the innovation processes of global corporations, enhance opportunities for the modernization of local parts and component suppliers. On the other hand, the passive strategies of final goods manufacturers that delay adoption of new products developed by the parent company with minimal contribution from the local subsidiary, increase the importation of components and discourage the modernization of local suppliers.

In the automotive industry, automakers based in Brazil have good automotive engineering practices, focused on the design of derivatives from engine, shift and suspension platforms, which are designed centrally in the countries of origin of the automakers. However, investments in innovation are relatively modest; for example, Brazilian automakers are not engaged in research or engineering of hybrid or electric-only vehicles. However, there are exceptions, albeit timid. Some companies, using the regulation of the electricity sector, carry out R&D projects through the R&D program of ANEEL. There are examples of greater activism: WEG, an electric motor manufacturer, has partnered with MAN to develop an electric truck and bus project. In contrast, domestic battery manufacturers, for example, do not seem to be concerned with batteries that are compatible with vehicular electrification, thus limiting their production to traditional lead-acid battery.

In this context, the most probable prospect for vehicles produced and sold in Brazil is the incremental change through greater absorption of embedded electronics; through the introduction of more efficient combustion engines designed abroad (three cylinders, turbo, etc.); or through some increase in the number of hybrid cars imported or possibly locally assembled. Hybrids are overcoming the charging infrastructure diffusion problem and therefore could be more quickly disseminated than non-hybrids. The growth of embedded electronics tends to lead to increased imports in the segment, as the Brazilian industrial structure is weak in the manufacture of more advanced electronic components.

It is an incremental innovation process that, in relative terms, does not take advantage of the technological change potential to increase the competitiveness of the automobile industry and its suppliers. More innovative initiatives by final goods manufacturers could induce significant competitiveness and productivity leaps along the production chain. Two examples of the importance of innovation strategies are the cases of an auto parts manufacturer that diversifies its production in order to provide electronic devices for multiple uses (Bosch) and of the manufacturer of major (white) appliances (Whirlpool), which carries out R&D in compressors in Brazil, as part of its innovation and global competitiveness strategy in final products.

In non-durable consumer goods there are opportunities to increase competitiveness and recover space in the domestic and international markets. In the textile, apparel and footwear industries as well as in the industry of processed food products, the dissemination of new technologies can have invigorating and positive impacts.

In the textile, apparel and footwear industries, the situation is quite heterogeneous. Large companies with capital-intensive processes coexist with smaller, labor-intensive producers, especially in the apparel industry. Brazil imports synthetic fibers and fabrics, which are increasingly used in apparel and footwear, and has been losing its share of world exports, including in the region. Scale and labor cost have been obstacles to increasing competitiveness in final footwear and apparel goods.

New technologies have the potential to positively change competitiveness conditions in Brazilian production in two directions. Firstly, the fact that these innovations can be introduced incrementally (sensors and artificial intelligence can be introduced on a machine by machine basis) reduces the importance of economies of scale. Secondly, digital base automation confers flexibility to processes, thus enabling product customization and increasing the speed of response to changes in retail. The stage of evolution of new technologies makes the pace of change conditional mainly on the capacity of producers to test new business models with active strategies of innovation, seeking alternatives to traditional suppliers, mainly in the provision of digitization solutions.

For smaller companies, the difficulties in adopting and disseminating new technologies can be associated with the lack of knowledge and limited resources of many manufacturers. In the absence of a process for the wide dissemination of new practices and of possibilities of low-cost access for specialized consultants and providers, the predictable scenario is one of diffusion restricted to a portion of producers. This may entail changes in market structures, with the disappearance of many companies and the destruction of assets and jobs.

The industry of processed food products is the weakest link in the country's agrifood system, despite the strong presence of global companies. Targeted at the domestic market and little integrated into global chains, the competitiveness of most Brazilian companies is still limited vis-à-vis best international practices. Innovation is essentially imitative in nature and largely reduced to the purchase of inputs and machinery, oftentimes through imports. However, this general scenario can be changed. National and global leaders have important research capacities in the country, including clusters that generate disruptive technologies. Two advanced segments in the Brazilian food industry are beverages and ready-to-eat food, with emphasis on companies with ambitions to consolidate their competitive position, including in exports. Companies like ABInBev, BRF, Mondalez, Ingredion, and Duas Rodas are quickly moving towards the use of IoT, AI and big data analytics. Their research lines converge with the priorities of global leaders: reducing or eliminating salt and sugar without losing texture and flavor, and developing new ingredients, aromas, and flavors. They are also engaged in digital marketing by automating the integration of their production, promotion and sales operations and joining social media. Even smaller companies have stood out for advanced activities in the creation of food ingredients and other biotechnological products.

Of all links in the agrifood chain, retail and foodservices will be transformed the most by the digital world in the short and medium term. The sector in Brazil is dominated by world leaders - Pão de Açúcar/Casino, Carrefour and Walmart - which have consolidated their capacity to use digital technologies in the organization of their supply chains and in attracting and retaining demand. In the country, despite all the transformations and turbulences of the first decades of the millennium, the digital world is increasingly becoming the modus operandi of retail.

The expansion of brand services - whether organically or through franchising - increases the demand for product standardization, giving rise to a market for food inputs that has already become key to the food industry in Europe and the United States. Despite the need to adapt to new criteria, it represents an important growth opportunity for the food industry while requiring fine logistics, for which traceability and IoT will be decisive.

The increasing value of fresh food opens up space for smaller producers. This, in turn, stimulates local agricultural production, whose clearest expression is the multiplication of producers' markets. New business models associated with product differentiation (organic food products, functional food products, natural food products, etc.) also provide opportunities for new entrants.

6.5 Our challenges, risks, and opportunities

6.5.1 Common challenges, risks, and opportunities

Producers of consumer goods present a wide variety of value chains, processes, products and markets, as well as large differences in terms of size, origin of capital, and competitive capacity. They share the common feature of targeting especially the domestic market. Integrated, connected and smart technologies that are relevant to producers of consumer goods - those associated with digital technologies, advanced materials and, in some segments, energy storage, nanotechnology and advanced biotechnologies - present opportunities but also - and especially - challenges for Brazilian industry.

They present opportunities because technological solutions are not necessarily implemented in complete platforms of the most advanced digital or biotechnological generation. The most advanced digital generation is not - and should not be - necessarily the solution to be adopted, with positive repercussions for the company's competitive position. And even if investment in new technologies accounts for a significant proportion of total investment, there are localized solutions that can be the subject of relatively simple return calculations. At the same time, complete solutions are also available, up to the limit of investment in a twin digital factory. However, in all cases the introduction of new technologies entails significant organizational changes.

They are also challenges in the sense that investment in new technologies requires knowledge about technologies and resources, as well as willingness to invest and a lot of learning effort on the part of entrepreneurs. In order to seize the opportunities provided by new technologies while preventing potential risks from materializing, investment in innovation must be a priority in the decisions and daily lives of entrepreneurs. A timid trajectory towards the adoption of new technologies is not sustainable from the business standpoint. In terms of the company's inclusion in the industry and its reflexes, attitudes of this nature weaken the country's international presence and disorganize local production chains.

Leading companies have a strategic role to play: they have resources, are linked to international best practices and can engage in the Brazilian ecosystem and in global innovation networks. This would result in the adoption of new production processes and in productivity leaps, in addition to ensuring Brazilian production a better position in the global scenario. Foreign companies with subsidiaries in Brazil and large nationally-owned companies with international presence are natural candidates to lead the development and adoption of innovations. This group is traditionally the transmission channel of technological and marketing innovations from the world to Brazil, and its innovation strategies tend to have spillover effects for the chain as a whole. They should therefore be encouraged to increase their R&D activities in the country. Strengthening the links between companies and technology institutions to enhance the innovation ecosystem will provide access to knowledge closer to the technological frontier, with positive impacts on the diffusion of disruptive technologies. The role of startups, especially spinoffs of research institutions, will be important in this process.

However, it is necessary to go further. Strengthening Brazilian industry requires accelerating and expanding the dissemination of innovations beyond the group of leading companies, so that productivity gains spread more widely across the productive structure. As many companies as possible need to keep up with the frontier of best international production practices. Even if the business group operates in market niches with low purchasing power and does not require quality standards as more demanding social groups do, it may be threatened by competitors which, by adopting new technologies begin to offer better products at more competitive prices. These threats have also been directed to pharmaceutical companies specializing in generic drugs, which will face competition from providers of low-cost products, but better suited for specific patient profiles.

The diffusion of new technologies should not be restricted to producers of final goods and services. They need to be adopted by parts and component suppliers, which are currently the weakest link in the production of consumer goods. It must also reach the production of final goods with relatively high labor costs compared to foreign competitors, in order to increase productivity. The dissemination of information on best practices used by competitors is indispensable here. Technology-based companies, especially startups, have a relevant contribution to make, because they know like few others the local environment and the challenges faced by the companies and are capable of developing innovative solutions and business models suitable for the group to which they are closely related. Their competencies are complementary to those of the leading companies, and they are a channel for the diffusion of innovations to manufacturers with less autonomous innovation development capacity.

6.5.2 Specific challenges, risks, and opportunities

In both the automotive and home appliance industries, it is important to strongly increase the productivity of parts and components suppliers to avoid disrupting the local supply chain. The dissemination of smart and connected production is the opportunity to strengthen the competitiveness of Brazilian industry.

In the automobile industry, the isolation of Brazil in relation to the adoption of powertrain technology can result in missed opportunities associated with consumer's demand for vehicles with different technologies. This isolation could lead to a decrease in the number of players in the Brazilian market, with the consequent decrease in both investments and production scale in the country. In turn, the adoption of flex hybrid vehicles could bring the Brazilian market close to electrification trends and thus create opportunities for the development of local technologies and productions: the country can be the pioneer of this model. The adoption of hybrid vehicles, in addition to mitigating isolation through electrification trends, is an interesting decision from the point of view of investment risk, vis-à-vis the electric-only vehicle that seems to be progressing (technically and financially) faster than expected.

The development of electric motors for heavy vehicles represents an opportunity for the country. Brazil has advantages for the development of electric and hybrid buses and trucks: a relevant potential market, an installed production chain and locally developed technologies. The development of these vehicles should target not only the domestic market but also the international market, with a view to gaining scale and scope that can ensure its competitiveness. Public policies and regulations in other countries should boost this market, creating demand for the adoption of these vehicles. This represents a unique opportunity for Brazilian industry, which is already an exporter in addition to being competitive.

The main challenge in the textile, apparel and footwear industry in Brazil comes from the low rate of innovation. Faced with the process of diffusion of new technologies already underway among Brazilian industry competitors, investing in innovative activities in general and in process engineering is a matter of competitive survival.

In the apparel and footwear industry there are also opportunities for the country to reposition itself in the global market in the medium term. The adoption of digital technologies, including of generations that are not at the frontier, can lead to qualitative improvements in productivity and competitiveness.

In parallel, for companies with greater capabilities there are opportunities in the development of smart fabrics and technical textiles. In this segment, the convergence of changes in processes, inputs and final products will result in the reorganization of the value chain. The materialization of this disruptive potential, however, will depend on the companies' capacity to implement new business models that are much more technology- and innovation-intensive. This requires: (i) investing in digital solutions for the modernization of existing equipment (digital retrofit) or investing in new generations that already incorporate new technologies; (ii) seeking knowledge and partnering with existing research institutes (e.g. CETIQT) to use new inputs in the development of products and their functionalities; and (iii) investing in solutions capable of connecting online and managing supplier and customer relations. As shown in the analysis of the digital technology diffusion process (Chapter 2), these are two organizational functions in which executives of Brazilian industrial companies foresee a greater probability of diffusion of digital technologies in the near future.

A major challenge for the food industry comes from the potentially negative implications of food products that go through various processing stages - including the most competitive segment of ready-to-eat food – which are seen as one of the causes of obesity and associated diseases. The Ministry of Health estimates that over half of the Brazilian population is overweight and 20% of Brazilians are obese. The industry is already committed to eliminating the ingredients and is developing new components from big data features and advances in genetic techniques.

Own or collaborative R&D efforts lead the food industry to use advanced biotechnology and synthetic biology techniques. The advantage, from the standpoint of research, is that until now neither new techniques (CRISPR/Cas9) nor the synthetic biology area have been subject to public regulation. Civil society organizations, however, are already targeting these new technological frontiers, and some iconic companies in the sector have already taken an opposing stand. It does not seem likely, therefore, that the launch of products based on these technologies will go unnoticed. Faced with the risk of these technologies being seen as an extension of genetic engineering, the production and circulation of components in laboratories will require clear protocols as well as a careful public awareness campaign; hence the need for the industry to start or engage in discussions about its regulation.

The food industry will shift to a trajectory of healthfulness, which demands the development of new processing concepts. Relying only on the names of familiar ingredients will be difficult, but some companies are already being guided by this goal. This challenge represents an opportunity for smaller innovative companies, in particular those that produce biological ingredients. Agricultural startups, which are already evident in digital services for agriculture, are the expression of a new model of the innovation ecosystem in the agrifood system as a whole, as it integrates into the digital world. This emerging model must be the subject of reflection and attention by development institutions.

As an important feature of an agrifood system subject to digitization, the establishment of niches for smaller companies in all their links is reinforced by the prioritization of fresh and natural products. In close conjunction with markets via applications, smartphones and social media, this new company profile is an intrinsic component of healthfulness. They do however require health criteria appropriate to their scale – and not simply the reuse of existing industry standards.

APPENDIX 1 – CURRICULA OF CONSULTANTS AND EXPERTS CONSULTED

CLUSTER: INTERNET OF THINGS

CONSULTANT IN CHARGE:

Antônio Carlos Gravato Bordeaux Rego (http://lattes.cnpq.br/5989160467865192) – An optical communication consultant, Mr. Rego holds a Bachelor's degree in Electrical Engineering and Physics from PUC-Rio, a specialization degree in Computer Networks from USP, and a Master's in Physics from Unicamp.

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APPENDIX 2 – ORDERED LOGISTIC REGRESSION MODEL

The logistic regression model is one of the most widely accepted methods to search for relationships among categorical variables, which makes it very useful for analyzes based on information from field surveys and research. Through logistic regression, the relationship between the categorical response variable (or dependent variable) and explanatory variables is given by estimating probabilities based on logistic functions. The result of this type of exercise is the estimation, based on the logistic function, of the probability of occurrence of a specific event associated with a target category of the response variable (LONG and FREESE, 2006, 2014). In the simple logistic regression version, only on explanatory variable is considered, which can be both quantitative and qualitative. Its multiple version considers a larger number of variables that best characterize the model. The dependent variable to be explained can have either two categories (binary dependent variable that takes on value 1 when the event occurs and 0 when it does not occur) or a greater number of categories (polytomous dependent variables).

Among the possible logistic regressions[8],[9], the choice for this methodological framework was the ordered logistic method, that is, the consideration of a model that respected the ordering of the dependent variable categories. This particularity is of special interest for the scope of this study, since it seeks to identify the determinants that confer greater probability of occurrence to more advanced movements between generations of digital systems for the period 2017 and 2027. Therefore, the response variable category of the so-called “digital” companies is considered to be higher than that of companies deemed “selective” which, in turn, is higher than that of companies classified as “analog”.

The basic version of the ordered logistic model is also known as proportional odds model or parallel regression model. This method assumes that the coefficients that describe the relationship between the different categories of the response variable are equal, which means that they are invariant at the cut-off points and that the effects of the parameters are the same between the different levels of the dependent variable and between the different estimated logistic regressions. Many times, these hypotheses are not tested, which implies using generalized ordered logistic regressions that ensure partial proportional odds[10] between independent variable categories (WILLIAMS, 2006).

8 Another model that allows for the analysis of polytomous dependent variables is the multinomial logistic model. The difference in relation to the ordered logistic method is that it disregards the order of the categories, treating them only as nominal categories.
9 According to Williams (2016), the ordering ability of the dependent variable can also be measured from an ordered probit. Both have similar approaches and what sets them apart is the way the cumulative distribution function is defined. Logistic regression is based on the logarithmic distribution whereas the probabilistic model uses the standard normal distribution.
10 In addition to the proportional odds and partial proportional odds model, Abreu et al. (2009) describe two other options of ordered logistic regression model: continuation ratio model and stereotype logistic model. The first, they argue, is more appropriate when there is a particular interest in a specific category of the response variable. The second is recommended when the ordinal response variable has no origin in the aggregation of continuous variables.

In the specific case of the exercise performed in Chapter 2, the proportional odds hypothesis was verified through the Brant Test. This test seeks to assess whether the deviations observed in estimates from the proportional odds model are greater than those attributed only by chance.

The result of the ordered logistic regression model provides the estimation of the coefficients associated with each independent variable. The usual interpretation of these coefficients is restricted because they cannot be analyzed in the same way as the coefficients of linear regression methods. In general, the degree of significance of the variables used to compose the model and the coefficient signal is evaluated as indicative of a decrease or increase in the probability of occurrence of the response variable in relation to the independent variable in question. Therefore, the option used in the proposed exercise was to work with the concept of average adjusted estimates of the probability of occurrence of a given set of events in relation to the categories of the variable to be explained. The derived results allow for more accessible and tangible interpretations for the construction of the analysis. Thus, specific categories of independent variables were selected to capture the odds of occurrence of each category of the response variable. This result is shown in Graph 1 of this chapter.

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FINAL REPORT

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VOLUME 2

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ABSTRACT

A changing world

The world is going through the first stages of deep **changes in production patterns, competition, business models, consumption and lifestyles**. The vectors of these changes can be found both on the demand side, stemming from population aging, from aspirations and frustrations of the middle classes, and from challenges associated with climate change; and on the supply side, stemming from faster **advancements in science and technology**, from the entry of **new players into international competition**, and from the **adoption of national proactive science, technology and innovation strategies** (ST&I).

International trade has grown and competition has increased significantly since the 1990s, when production in certain industrial sectors became increasingly fragmented geographically into what came to be known as global value chains. Companies in advanced industrial countries outsourced production and focused on the sophisticated links of value chains. New manufacturing companies, mainly in Asia, entered labor-intensive stages, exploiting cost advantages. However, over the subsequent decade Asian companies automated their processes intensively, accumulated economies of scale and promoted advancements in research and development (R&D) that enabled them to compete for global leadership in several segments, such as in the information and communication technology (ICT), Internet access devices, microelectronics and consumer durables segments.

These geoeconomic changes led to the emergence of **decentralized and sophisticated production structures**. Leading companies in the global value chain have engaged partners (domestic and international companies and research institutions) in **multi-partner, interdisciplinary and internationalized innovation ecosystems**. The ecosystems on the technological frontier are characterized by multiple and dense links of cooperation, interdisciplinarity, and participation of international centers of excellence.

At the same time, **the pace of technical progress has gained speed**. Clusters of combined and synergistic innovations are emerging **with sufficient strength to produce disruptive effects** on business models, on the determinants of competitiveness and on market structures in all productive activities. **What are these innovations all about?** What are their constituent elements? How do their costs and markets evolve? What is the rate of their dissemination? Is this disruptive potential already being felt in all technologies and in all productive activities?

Have these **innovations** emerged as "natural" processes or **are they being built** through long and persistent interactive processes between the world of science and technology, the business world, and the world of public policy? To what extent do these processes **anticipate and respond to societal challenges** or to the demands of competition and markets? Is it possible to identify **new business models** adopted to take advantage of opportunities derived from these new technologies? What **key factors** will determine **competitive success**? What changes can be expected in market structures when these technologies become economically relevant? Are incumbent companies systematically seizing these new opportunities or are they being threatened by new entrants?

Answering such questions is an essential step in a project designed to build the future of Brazilian industry.

What are combined, synergistic and disruptive innovations?

Solutions combining and leveraging knowledge-intensive innovations are being introduced and disseminated to create new markets and new business models, leading to significant social and economic impacts. The ability to tackle technical challenges increases significantly when different scientific and technological bases are combined: for example, genomics with high performance computing for DNA sequencing; advanced microprocessors for image recognition with robotics for self-driven vehicles; or the Internet of Things (IoT) with artificial intelligence and advanced communication networks for smart grids and traffic control in urban centers.

Despite differences in their knowledge bases, all technological solutions with disruptive potential have two **elements in common: sharply falling costs and fast-growing markets**. For example, the cost of sequencing human genomes fell from US$95 million in September 2001 to US$1,000 in September 2017. The average cost of sensors for the IoT was US$1.30 in 2004 and it may drop to as low as US$0.38 in 2020. The cost in US$/KWh of lithium-ion batteries declined from US$1,000 in 2010 to US$209 in 2017. In 2017, sales of big data solutions were estimated at US$34 billion and they could triple in eight years. Expenditures with robotics are also likely to triple by 2025 to US$70 billion.

The prospective evaluation carried out under the Industry 2027 project suggests **that all productive systems will be coexisting with disruptive technologies in up to ten years. Although time is scarce, Brazilian industry can and should prepare for these approaching changes in technology.**

The **business models** of companies and their value chains are **evolving into integrated, connected, smart and "servitized" models**. They are integrated and connected because the different links of value chains and intra-company activities will become so close that their boundaries are tending to disappear. They are smart because economic and technical information will be captured and processed online, making it possible for decisions on actions and reactions to productive phenomena to be delegated to digital equipment and systems through artificial intelligence algorithms. Models of this nature make it possible for companies to provide intrinsically complementary goods and services or to offer goods to be used in the form of services instead of selling them.

Such models are paving the way for companies to support their strategies with **new competitive factors**: in processes and value chains, these new technologies make it possible to **optimize the management of the entire chain and enhance the accuracy of efficiency parameters**, combine **scale with differentiation and customization** and, in the limit, **customize products**. For example, precision agriculture and personalized medicine are concepts that have become operationally feasible based on clusters of combined and synergistic innovations.

Under increasing competitive pressure, companies need to transform themselves and adopt new business models. As a result, **market structures have become more vulnerable to the entry of new competitors into the market**, more flexible in the face of different business formats, and more permeable to leadership changes.

National strategies for building futures

Never before have so many countries prioritized science, technology, and innovation as today. The United States intends to maintain its leadership in the field of ST&I and regain manufacturing capacity. Public and private spending on research and development (R&D) in 2018 is estimated at US$533 billion (2.7% of GDP). In China, this spending is estimated at about US$279 billion (2.3% of GDP) and it tends to grow. The Made in China 2025 plan will not be over this year; it is the country's ambition to become a world superpower by 2049. Germany, which is known for its *Industrie 4.0* initiative, has plans to strengthen the hegemony of its mechanical and chemical industries, among others. German investment in R&D in 2017 was estimated at US$105 billion (2.8% of GDP).

Despite differences in legacies and ambitions, a comparison between countries with a strategy underway reveals common foci, namely: sustaining international competitiveness, developing innovation ecosystems, creating jobs and qualifying people, supporting smaller companies, paying attention to the quality of life, health and aging of the population and ensuring environmental sustainability. **These future-building strategies are linked by common national views, led by the highest executive authorities in each country, supported by public-private consultations, and rely on significant and predictable funds earmarked for them**.

The opportunity of Industry 2027

A changing world, more intense international competition based on innovation, technology clusters emerging with disruptive power, and countries implementing strategies to promote productive and innovative ecosystems have led the National Confederation of Industry (CNI), through the Euvaldo Lodi Institute (IEL), under the Entrepreneurial Mobilization for Innovation (MEI), to mobilize the Economics Institute of the Federal University of Rio de Janeiro and the Economics Institute of the State University of Campinas to carry out the **"Industry 2027: risks and opportunities for Brazil in the face of disruptive innovations" project**.

The Industry 2027 project identified trends and **impacts of disruptive technologies** on different production systems in a five- to ten-year horizon; assessed the capacity of companies to deflect risks and **seize opportunities**; and developed recommendations for the strategic planning of companies and inputs for public policy making.

The study was focused on technology clusters and production systems with sectoral foci. **The technologies that were studied were defined based on their potential disruptive impact** and organized into eight technology clusters based on the similarity of their technical bases. **Industry was stratified into ten production systems and 14 specific sectoral foci** selected according to the economic importance of the activities in question for the country's industrial matrix and to the potential impact of innovations on each of them.

These clusters are the following ones: Artificial Intelligence, Big Data, Cloud Computing; Internet of Things and its respective systems and equipment; Smart and Connected Production (advanced manufacturing); Communication Networks; Nanotechnologies; Advanced Bioprocessing and Biotechnologies; Advanced Materials and New Energy Storage Technologies. The production systems and sectoral foci are the following ones: Agroindustries and Processed Food Products; Basic Inputs and Steelmaking; Chemicals and Bioeconomics; Oil and Gas and Deepwater Exploration and Production; Agricultural Capital Goods and Machinery and Implements, Machine Tools, Electric Engines, Energy Generation, Transmission and Distribution Equipment; Automotive Complex and Light Vehicles; Information and Communication Technologies and Systems and Telecommunications Equipment, Microelectronics and Software; Pharmaceutical and Biopharmaceutical Products; Consumer Goods and Textiles and Wearing Apparel.

During **14 months**, since March 2017, a team of 75 experts of recognized competence in technologies, industrial sectors, and innovation policy was mobilized in Brazil and abroad to contribute to Industry 2027. A field survey was carried out with approximately 750 industrial companies in the second half of 2017. Well-informed representatives of these companies expressed their opinions on the current stage and prospects of digitization in their companies. **The development of the Industry 2027 project was monitored by MEI** at all meetings of leaders and MEI Dialogue sessions. A supervisory committee monitored its implementation and defined strategic guidelines; the reports were enriched by inputs from the technical teams of CNI, IEL and SENAI, and IEL ensured the project's timely implementation. **These are the main assets of the Industry 2027 project: the knowledge and competence of well-informed and specialized professionals**.

Two warnings should be made at this point. First, this project mainly considered technological solutions that could be commercially available by 2027. Solutions that may only become available after 2027 were not analyzed in depth. Second, changes that technical progress will bring about in other dimensions of economic and social life were not directly considered. Impacts on consumption patterns, on the labor market and occupations, and on the regional configuration of ecosystems, for example, were only considered when deemed relevant to the competitiveness of companies.

Challenges for Brazilian industry: chasing moving targets

Brazilian industry is characterized by a diversified and differentiated framework; its productive systems and even each economic activity are marked by the coexistence of companies with varying levels of capacity and competitive performance. Thus, it is not possible for it to use only the most advanced generation of digital manufacturing technologies as a benchmark, as Germany does.

The Industry 2027 project carried out a prospective analysis of the digitization stage of Brazilian industry, distinguishing between four generations of digitization (G1, G2, G3 and G4), ranging from that of isolated digitization (G1) to integrated, connected and smart companies (G4). Representatives from approximately 750 companies reported (i) the stage in which their companies were in 2017 and the stage in which they expected them to be by 2027; (ii) how their companies are preparing for the future; and (iii) what is, in their opinion, the likelihood of the most advanced generation becoming dominant in the sectors in which their companies operate. The most important results are the following ones:

- According to 65% of the companies' representatives, G4 will become dominant in sectors in which their companies operate by 2027. They suggested, therefore, that their companies will face competitors with integrated, connected, and smart business models.
- In 2017, approximately 75% of the companies are in the G1 and G2 stages; only 1.6% of the companies see themselves as operating in the G4 stage. The starting point is therefore challenging.
- In 2027, major advancements are expected: approximately 60% of the companies expect to be in the G3 or G4 stage in the future. Forced-march modernization is expected.
- Advanced companies (G3 and/or G4 in 2017 and by 2027) are 66% more likely to be larger, have high capacity, and have plans underway to implement systems of the expected generation; passive companies (G1 and/or G2 in 2017 and by 2027) are 75% likely to be small, have low capacity, and have no plan in place.

- Regardless of the structural or behavioral characteristics of the companies, investing in new technologies provides a positive return; these new technologies can be implemented gradually, according to the availability of funds and to the stage of development of the organizations, but such action should not be postponed.

The analysis of production systems of the Industry 2027 project was carried out in three consecutive steps: (i) identification of risks and opportunities for each of the ten productive systems (and their sectoral foci); (ii) comparative analysis of the systems, grouped into four groups of sectors selected according to the similarity of their function or to the nature of the activities they carry out in the economy, namely, innovation diffusion sectors, specialized and advanced knowledge activities, producers of intermediate inputs, and suppliers of consumer goods; (iii) location of groups of companies (and their structural characteristics in terms of production system and size) in three different stages of development, distinguishing between companies evolving on the technological frontier, companies capable of keeping up with the productivity frontier, and companies that need to get closer to the productive efficiency frontier. The distances from the technological and productive frontiers were the anchors based on which recommendations were issued for business planning and public policies.

Assumptions for building the future

International experience shows that building robust national innovation strategies requires consensus on a common national vision. These strategies must be built on existing legacies, recognizing weaknesses and strengths; they must set ambitious goals and targets to take advantage of opportunities; and they must be realistic and pragmatic in the actions they contemplate.

For these strategies for new technologies to be actually implemented they require: (i) prioritization at the highest level of government and the existence of shared goals with private-sector counterparts; (ii) substantial investments in training human resources; (iii) enforcement of regulations and pro-innovation incentives; (iv) modernization and increased response capacity on the part of the State; and (v) implementation of actions through programs and instruments coordinated and aligned with the needs of companies and monitoring of their results.

Naturally, fundamental conditions to facilitate the implementation of these national strategies include resuming sustained economic growth with competitive interest and exchange rates; increasing investments in infrastructure and institutional reforms (tax, fiscal, financial reforms); ease of doing business and legal certainty. However, the country's administration should not condition the implementation of a national innovation strategy to the existence of these systemic conditions. The innovation strategy must be given high priority and involve persistence and a long-term vision, apart from being preserved even during unfavorable cyclical stages.

Moving targets: implications for companies and public policies

In addition to common directions, companies close to the technological frontier or to the productivity frontier and those that need to shorten distances from the production frontier face quite different competitive challenges. These groups of companies face distinct demand and competition pressures, have different skills, and operate in specific production and innovation ecosystems. Obviously, the implications for competitive strategies and public policies will also be specific for each group.

For **companies and ecosystems that can evolve on the technological frontier**, the recommended strategy is that of competing for differentiation, anticipating or creating markets, and remaining on the alert for opportunities for mergers and acquisitions with the aim of acquiring new competencies. Key competencies to be stressed here include those of generating, using, and disseminating advanced innovations and different knowledge bases through investments in R&D and by co-leading networks of production and innovation ecosystems, including day-to-day control and monitoring by the senior management of the organizations. These ecosystems should strive to strengthen the scientific and technological base of interdisciplinary networks (including international ones) with universities, research centers and suppliers; favor startups in hubs and business incubators; and identify challenges and propose solutions speedily. For this purpose, it is necessary to promote public-private concertation around programs and plans, which requires building consensus between public and private interests; implement actions through programs with specific foci and specified leaderships, in fine tuning with the private sector; carry out joint actions with development and regulatory agencies; and monitor and evaluate results on an ongoing basis. With respect to financing for disseminating technological solutions designed to promote productivity gains in the economy, securing public finance and private engagement is recommended using all the available instruments, such as subsidies, credit, and venture capital, to support the innovation cycle as a whole with co-participation of the private sector for the purpose of sharing risks. Large enterprises should also engage in corporate venturing with technology-based companies. Finally, regulations should be designed to foster innovations that exploit technological frontiers and public procurement should be guided by missions for priority programs associated with new technologies.

For **companies and ecosystems capable of keeping up with the productivity frontier**, the recommended strategy would be that of investing in integrated, connected, and smart business models covering the entire value chain to maximize productivity gains and sustain international competitiveness. Key competencies for these companies include engineering and R&D skills and market knowledge to seize product/service differentiation opportunities and use (or co-develop) new materials in advanced digital components and solutions and day-to-day control/monitoring by the senior management of the organizations. These ecosystems should give priority to engineering and R&D and to identifying challenges and proposing solutions speedily; they should also favor startups in hubs and business incubators in the long-term and make efforts to evolve into interdisciplinary networks with research centers, suppliers and customers. With respect to financing, organizing public funding for risk-sharing programs with the private sector is recommended. Companies should also invest in launching and/or advancing in the use of digital technologies, complementing public funding, and they should strive to engage in corporate venturing with technology-based companies. Regulations should be designed to ensure precision, quality, safety (including data), and environmental sustainability.

For **companies and ecosystems that need to draw closer to the production frontier**, the recommended strategy involves investing in knowledge and implementation of digital solutions to gain productivity while strengthening business management and the ability to deliver quality and price efficiently. For these companies, the key competencies are the capability to manage their business, especially their production, and having the required knowledge to specify and implement more appropriate technological solutions for their business. For the advancement of ecosystems, it is recommended that public and private technological support institutions and the SENAI Institutes take on the role of leading networks and motivating companies, with specialized technical service centers playing the role of providing digital solutions to promote basic industrial technology and institutions that support business management, such as SEBRAE, fostering massive dissemination of new practices associated with digital technologies. It is imperative that participants in production chains (especially large upstream or downstream companies) take part in these ecosystems to qualify their suppliers or customers and that experiments to demonstrate digital solutions such as production lines and testbeds are promoted. With respect to financing, it is crucial to promote favorable credit conditions to finance the purchase of equipment, software, system integration services, and other appropriate digital services for companies and ecosystems. To foster the dissemination of new technologies, programs for the provision of specialized technical services should be oriented to tackling specific challenges associated with basic industrial technology, with expansion goals organized into networks (for example, SENAI networks), and programs in support of business management (such as the More Productive Brazil program) should be massively and significantly expanded with the aim of disseminating digital solutions appropriate to the profile of the companies with spatial, sectoral, or thematic foci and duly established goals and counterparts. With regard to regulations, they should be designed to induce the supply of externalities.

Building foundations for all

With regard to **human resources training**, it should be pointed out that the Brazilian public and private professional training system, especially SENAI, are strategic agents to improve the qualification profile of Brazilian workers. Steps must be taken toward (i) evolving from "training centers" to "learning centers"; (ii) expanding and diversifying professional training programs to develop and renew skills throughout workers' lives; (iii) anticipating an preventing needs in terms of skills and talents of workers and companies; (iv) including learning and use of digital technologies at all levels of education; and (v) promoting studies and debates on the impacts of technical progress on occupations, qualifications and labor, income and social benefits.

In order to **build capacity in small and medium-sized enterprises (SMEs)**, it is necessary to massively expand programs on entrepreneurial training, technical assistance, and technical/metrological services, such as the More Productive Brazil program. These programs should be designed to promote rules and standards designed to facilitate the dissemination of new technologies, ensure interoperability, and guide the operation of existing networks that provide assistance to SMEs. It is also necessary to disseminate integrative digital solutions and software, modular experimental platforms, including for lean manufacturing and energy efficiency, through the SENAI network of Technology Institutes and Innovation Institutes in partnership with SEBRAE, and to finance such solutions through public financial institutions. In order to build capacity in SMEs, it is necessary to mobilize credit, grant, and venture capital instruments with the aim of structuring permanent engineering and R&D activities in these companies. Finally, the need to strengthen incubator and accelerator networks and ensure favorable tax treatment to venture capital funds should be emphasized.

With regard to **regulatory aspects**, there is a need for contemporary and efficient regulation, which fundamentally requires updating legal frameworks for communications, ST&I, government procurement, biodiversity, network privacy and security, research and applications derived from advanced genomics techniques, and the "Civil Framework for the Internet of Things." There is also an urgent need to speed up the process of building capacity in and digitizing regulatory agencies/public companies, particularly the National Institute for Industrial Property (INPI), the National Health Surveillance Agency (ANVISA), the National Telecommunications Agency (ANATEL), and the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA).

With regard to **sectoral agencies**, urgent steps must be taken to converge and standardize normative concepts related to innovation and R&D (including those adopted by the Brazilian Federal Internal Revenue Service), with a view to increasing efficiency and legal certainty. In addition, sectoral funds managed by sectoral agencies should be made available on a predictable basis and partnerships should be forged with funding agencies around challenge-driven technology development initiatives organized by programs, in line with the successful experiences of the Brazilian Company for Industrial Research and Innovation (EMBRAPII) and of the Inova Empresa program, with more non-reimbursable funds.

In order to **promote development with legal certainty**, it is necessary to decompress federal funds allocated to the ST&I system and define priority projects and programs at the highest levels of government, with goals shared with the private sector. It is recommended that the scale of support to innovation provided by federal financial institutions is increased through financing, including through non-reimbursable finance, and capitalization at appropriate costs and conditions (examples such as those of EMBRAPII should be strengthened and expanded), so as to ensure the availability of funds during all the different phases of priority projects, especially during the scaling up and manufacturability phases. For this purpose, provision should be made for allocating additional funds - on a predictable basis and without the possibility of the Federal Government using them to pay other bills or reduce spending - to building capacity in public and private science and technology institutions. It is also recommended that the Law of Good is improved by increasing its deductions, allowing for external R&D to be partially hired, including incentives for investing in startups, seed capital, angel investors, venture capital, etc. In addition, in order to ensure legal certainty and for companies to enjoy the incentives provided for in the law, it is important to ensure the convergence of legal concepts and rules to standardize enforcement criteria.

An integrated, connected and smart State - a digitized State - is required to promote efficiency gains, cost reduction, transparency, quality, and agile services (red tape reduction). This requires building capacity in public managers to prospect, plan, implement and evaluate programs to promote the generation, use and diffusion of new technologies. It also requires efforts to coordinate agencies and institutions and ensure consistency in the management of financial and non-financial instruments through integrated, smart, and transparent management systems.

International experience shows that **society should discuss new ethical and regulatory issues**. Because such new topics require attention, it is recommended that comprehensive and representative discussions and public consultations are held to validate proposals for: interoperability of standards and protocols, database ownership, personal privacy, communications and information security for companies, use and manipulation of human, animal and plant genomes, property and rights of protection of genomic data or of biodata of people or living organisms, recycling of inputs, parts and pieces and equipment related to bio- and nano-materials, and digital technologies.

Brazil can and should build the future of its industry

Countries intending to play a prominent role in a multipolar and competitive international scenario build their future proactively based on long-term, stable national innovation strategies legitimized by their respective societies and managed at the highest levels of government.

Brazil has no more time to lose: the powerful wave of ongoing technological innovations exposes risks of setbacks and opens up opportunities. If Brazilian industry doesn't keep pace with this wave, it runs a serious risk of losing substance, leading society to give up achieving more added value (wages, profits, taxes) and generating new services and jobs.

On the other hand, combined and synergistic innovations provide several windows of opportunity for Brazilian industry to develop new specializations and strengthen its competitive capacity on a sustainable basis. There are sectoral peculiarities and, after studying them, it was possible for the I2027 project to indicate how the response capacities of the private sector can be strengthened. Based on a broad mapping of international experience contemplating successful programs and initiatives, appropriate foundations for building public policies were specified and their political requirements were duly explained in detail.

There is nothing preventing these opportunities from being seized, except our own ability to establish a solid and persistent national strategy. Brazil can and must make progress in seizing these opportunities with ambition, realism, pragmatism, resilience, focus, and a long-term vision. For this purpose, a solid partnership must be established between the state and the private sector and legitimized by society around positive paths to be followed in the future.

The path of competitiveness has been established; respecting the specific features of competition in each market, a competitive company is and will always be an integrated, connected, and smart company. The future is built through investments in capacity-building and R&D, based on long-term plans tenaciously implemented on a daily basis.

The new technologies pave the way for Brazilian industry to develop skills and seize opportunities to compete, create new services, generate jobs, and contribute to improving the quality of life of our people.

INTRODUCTION

Over the last decade, the pace of technical progress has gained steam with the emergence of innovation clusters producing disruptive impacts on business models, on the determinants of competitiveness, and on market structures in all productive activities globally. Describing these innovations and analyzing their multiple effects on production systems and key sectors of the Brazilian economy were the objectives of Volume 1 - *Disruptive Technologies and Industry: Current Situation and Prospective Evaluation*. Volume 2 - *Disruptive Technologies and Industry: Challenges and Recommendations*, which has a propositional character, is in turn intended to analyze the determinants of the current international division of labor in industry, the contemporary role of innovation ecosystems, and the status of capabilities in the face of the challenges and opportunities brought about by disruptive innovations. Reviewing ongoing innovation strategies in several relevant industrial countries contributes to supporting policy recommendations applicable to Brazil.

Chapter 7, which opens this Volume 2, discusses geoeconomic changes leading to the emergence of decentralized and sophisticated production chains, as well as to interdisciplinary international innovation ecosystems with multiple partners and participation of research centers of excellence. At the current stage of global competition, advanced industrial countries have been devising national assertive ST&I strategies to remain on or regain the lead in advanced manufacturing and cutting-edge technology sectors. Ecosystems on the technological frontier are characterized by multiple partners, dense cooperation links, and technological interdisciplinarity.

Structuring and fostering ecosystems capable of generating innovation depends critically on the availability of highly skilled human resources. The status of human resources and capabilities in the face of disruptive innovations is the subject discussed in **Chapter 8**. It addresses not only the need for continued education for undergraduates, masters, and doctors in science, engineering, mathematics, and the indispensable availability of highly qualified scientists and professionals in companies, particularly in their regular engineering and R&D activities. It also discusses how innovations affect the skills required of workers and change the nature of labor and labor relations, with varying effects on the characteristics of the education and qualification of workers (contents, curricula, competencies developed), as well as on the professional trajectories and evolution of workers throughout their working lives.

Thus, in order to cope with the breakthrough of disruptive innovations and with the intensification of international competition, several countries adopted large-scale strategies designed to strengthen and reposition their economies. However, these strategies are driven by a long-term vision and address industrial development and innovation not as an end, but as a means to achieve ambitious goals: transforming not only the industrial system, but society as a whole. Therefore, they address major societal challenges, such as population aging, education and employment, health and quality of life, reduction of regional inequalities, energy security, and climate change. These national strategies are analyzed in detail in **Chapter 9**, which in identifying recurring topics provides some lessons for developing a Brazilian national strategy.

Next, **Chapter 10** identifies, within the Brazilian innovation system, major public and private actions taken in the recent past and initiatives currently underway, as well as consolidated institutional structures that could be mobilized for developing and implementing a Brazilian national strategy in the face of disruptive innovations. While in the last two decades Brazil resumed strategic plans in which technological innovation was the main factor for increasing productivity and promoting growth, the development of a more far-reaching national strategy was interrupted during 2015-2017 due to a serious economic and political crisis that severely affected the Brazilian S&T system and its incipient synergy with the business sector.

The challenge is huge: steps must be taken to address it at the same speed as that of the technological frontier or greater, otherwise we will be losing even more ground. It will only be possible to resume and boost industrial development by taking a major leap in promoting innovation. **Chapter 11** proposes paths and provides recommendations for building the future of Brazilian industry. It discusses how the effort to build the future of our industry must be based on the legacies of entrepreneurial, scientific, and technological competencies and existing capabilities in our innovation ecosystems. Based on lessons learned from international experience, it is argued that innovation strategies must be supported by close public-private concertation and that they require the engagement of government at the highest levels to secure significant, stable, and predictable financial resources on a long-term horizon. That chapter also provides guidelines and strategic proposals for the three groups of companies and respective production and innovative ecosystems analyzed in this project. It also specifies relevant development, regulatory, and financing instruments to be adopted for each company category/ecosystem considering their specific stage of development in relation to their capacity to compete and innovate.

A **Final Message** closes this Volume 2: we are sure that our ability to establish a solid and persistent national strategy is what will make it possible for us to seize the windows of opportunity afforded by the disruptive innovations analyzed here. For this purpose, it is essential to establish a solid partnership between the State and the private sector and to make sure our paths for the future are legitimized by society. Brazil can and must advance with ambition, realism, pragmatism, resilience, focus, and a long-term vision.

7

IMPACTS OF DISRUPTIVE INNOVATIONS ON GLOBAL VALUE CHAINS AND THE INCREASING IMPORTANCE OF INNOVATION ECOSYSTEMS

7.1 In what ways can disruptive innovations impact on global value chains?

The conclusion of the GATT Uruguay Round in the mid-1990s paved the way for profound changes in the international trade and investment regime and brought about major changes in the map of industrial goods production in the world. The new trade regime and advancements in digital data communication and processing have made it possible for production and consumption to be geographically fragmented in many major manufacturing chains. Industrial enterprises were able to exploit a new style of production internationalization by combining specialization within their networks of branches (intra-firm trade) with outsourcing from independent suppliers from other countries. As a result, international trade in industrial, intermediate, and final goods has grown exponentially.

At the same time, reforms carried out in China and the Asian urbanization and industrialization process offered a gigantic frontier for expanding industrial activity on a global scale. Large manufacturing companies from the United States, Europe, and Japan transferred a significant portion of their production to plants located in South Korea, Taiwan, Singapore and, increasingly, China. The latter rose rapidly and became the main global base for producing and exporting manufactured goods.

More consolidated industrial goods markets and more intense competition increased the importance of cost advantages, particularly those resulting from the production scale. **Global value chains** (GVCs) emerged as an efficient solution for large-scale, geographically deverticalized and specialized production with the participation of independent producers. In some cases, GVCs are run by large, partially integrated industrial companies; in others, by fabless companies, which only have intangible assets (such as engineering and design of differentiated products and their brands), or by companies that own marketing networks.

Multilateral, regional, and bilateral trade and investment agreements were shaped to make it possible for GVCs to be expanded. Companies and countries sought opportunities to include themselves in the new industrial activity map.

From the point of view of the companies leading the chains, the competitive advantages of potential participants were reconfigured:

- In the initial (upstream) links, the availability and cost of raw material exploitation or the cost of processing industrial inputs are key factors. In both cases, the quality and cost of the logistics infrastructure condition the insertion of producers.
- In the intermediate and final (downstream) links, labor costs, regulation, taxation, and tax incentives are factors conditioning the insertion of suppliers of parts, components, and manufactured products.

The ability to innovate, integrate dynamic innovation ecosystems, and anticipate the emergence of new businesses are decisive factors in the struggle for value capture within value chains. Precisely these factors support the ability to lead or operate more favorably in GVCs.

The emergence of GVCs relativized the importance of having a large domestic consumer market as a factor that attracts industrial producers. On the other hand, the importance of other factors such as the availability of human resources and infrastructure for innovation, scientific and technological capacity-building, and the existence of robust and dynamic innovation ecosystems has increased.

The fragmentation of production and consumption of industrial goods has led to trade imbalances and job losses in industrialized countries. Countries with large consumer markets such as the United States, for example, have accumulated significant trade deficits in manufactured goods. On the other hand, China has centralized much of the global industrial output. These large imbalances fuel tensions between countries and are already triggering serious trade conflicts, leading to changes in the international economic order built since the 1990s, particularly in the current structure of GVCs.

Clusters that generate disruptive technologies are another potential factor of change in the structure of GVCs. The digitization of industrial production driven by advancements in AI, networks, IoT, and SCP may have a strong impact on the manufacturing and assembly activities that characterize the downstream links of GVCs. Disruptive technologies result in new products (capital goods and consumer goods), while smart and connected products generate business models linked to new services. Disruptive technologies also affect manufacturing processes not only by increasing automation levels and flexibility, but also by increasing product customization without losses in economies of scale.

The disruptive impact of new technologies on GVC links in which components are manufactured and final products are assembled, such as on automotive, aeronautical, capital goods, and apparel industries, is potentially very important. New technologies change products and manufacturing processes, altering the determinants of competitiveness and the insertion of companies and countries in GVCs. In the automotive industry, mastering technologies associated with conventional motorization has become relatively less important, and the same can be said of the apparel industry in relation to the cost of labor. The ability to deal with digital technologies has become more important in both cases.

In processing industries, such as in those of basic inputs, chemicals, agrifood, and oil exploration and production, which characterize the upstream links of GVCs, the impact is relatively smaller. In these activities, significant progress has been made in process control digitization and automation. Even so, disruptive technologies will result in significant efficiency gains and cost savings in production and logistics. New technologies also contribute to solutions for reducing the impact of processing plants on the environment. In addition, nanotechnology and biotechnology make it possible to develop advanced materials with important functional characteristics for new products.

Trade and geopolitical tensions arising from recent US initiatives and the disruptive potential of new technologies tend to bring about changes in the industrial production and consumption map between now and 2027. Companies and countries are making an effort to redesign GVCs by exploiting the opportunities afforded by new technologies to improve their insertion in them.

The disruptive nature of new technologies strengthens the competitiveness of companies and countries capable of identifying, devising, leading, and exploiting emerging opportunities. **The convergent nature of the various technologies involved, the evolutionary stage in which they are today, and their wide range of possible applications enhance the importance of relying on dense and dynamic innovation ecosystems** capable of quickly harnessing resources from several areas of knowledge, as well as from companies and institutions with different profiles and focused on new business opportunities.

7.2 What are innovation ecosystems and how important are they?

A common feature for public and private initiatives to win or improve industry positions in global value chains in the realm of disruptive technologies has been that of strengthening and/or **setting up qualified and efficient innovation ecosystems**. An innovation ecosystem consists of a network of institutions - companies, universities, research institutes, development agencies, consumers, service providers, suppliers, among others - interconnected in a business environment and focused on an innovative company or technological platform with its own dynamics and which adds value to each of its members and to the community as a whole through innovations (KOSLOSKY *et al*, 2015).

There are reasons for the prevalence of these common characteristics among innovation ecosystems: a significant increase in the interdisciplinarity (or multidisciplinarity) of scientific and technological processes results in an increase in the number of participants in collaborative R&D networks (both of business and public actors), requiring a more efficient coordination of ecosystems (ESs) with the aim of maximizing their synergies.

Not only does the number of actors in the ecosystems increase, but also their diversity, involving companies and institutions with different profiles and specializations. In addition, cooperation links and the frequency and density of relations, including international cooperation ties, multiply themselves.

In fact, collaborative networks in the scientific field have gained a significant international dimension through cooperation arrangements established between centers of excellence of different origins. At the same time, companies leading innovation ecosystems seek to engage partners (domestic or international partners) with complementary and diverse technological capabilities. These factors have made it more challenging to combine the externalities and synergies derived from collaborative networks making up ESs, requiring attention in domestic innovation policies.

The interdisciplinarity and complexity of ST&I processes are significantly important factors in the case of the technology clusters covered in the I2027 project. There is no doubt that these technologies combine knowledge from a wide range of scientific and technological fields - such as research into nanotechnologies, advanced information and communication technologies, and genomics, which are inherently interdisciplinary.

In addition, as seen in Volume 1, joining together and combining digital technologies (supercomputing, microelectronics, software, artificial intelligence, and cognitive processes) tend to generate disruptive impacts, originating new products derived from biotechnologies, nanotechnologies, materials, energy storage, and new production, operation and management processes induced by advancements in the IoT and in smart and connected production.

Considering these trends, several countries have been promoting programs, financing mechanisms, and actions to stimulate interdisciplinarity and interinstitutional collaboration. In many cases, these programs are accompanied by the provision of laboratory infrastructures, demonstration plants, and advanced simulation systems to support the scaling-up of innovations (O'Sullivan *et al*, 2017; OECD, 2017).

Strengthening innovation ecosystems implies not only stimulating interdisciplinarity in research activities, but also redefining the content of education and qualifying technical workers and engineers, as interdisciplinarity requires more versatile human resources with a broader range of knowledge and skills.

For all of these reasons, entrepreneurial and domestic strategies to improve competitiveness and positioning in GVCs give priority to fostering interaction between the companies and institutions that make up the R&D and innovation networks of the ecosystems. Given the convergent, integrated, connected, and increasingly smart character of disruptive innovations, collaboration between research institutions, universities, companies, customers, and suppliers is vital for developing, transferring, and disseminating technologies.

As scientific advances become increasingly global in nature, international collaboration becomes more and more relevant to innovation ecosystems. However, this does not mean that the domestic dimension has become less important, since financing, promotion, and regulation policies are intrinsically governmental and guided by domestic objectives. Moreover, the decision-making centers of the companies and/or institutions leading these ecosystems are situated in their respective domestic spaces. In addition, interactions occur more easily within their respective countries, under the influence of cultural and social elements.

7.3 Innovation ecosystems in Brazil: what is their current status and what opportunities are available?

In Brazil, there are few organized ecosystems led by companies and ST&I institutions close to the frontier of disruptive innovation with the capacity to not only keep up with it, but also to create paths beyond it. These advanced Brazilian ecosystems are precious and should be firmly and continually supported by both the business system and long-term innovation policies. Brazil also has several ecosystems with high potential to draw creatively close to the innovation frontier; however, they are still marked by weaknesses and lack of appropriate links, but given their respective potentials they should also be supported by the public and private sectors on a firm and sustained basis.

In the Brazilian case, however, the vast majority of ecosystems are in a relatively precarious situation, lacking appropriate links. Several of them rely on qualified public research institutions, but they are weak in terms of private-sector R&D capacity. In other cases, there are companies wishing to structure R&D activities, but they lack sufficient support from ST&I institutions. In other words, most ecosystems in Brazil are unbalanced and have gaps, resulting in the rarefaction of innovation activities.

Therefore, the temporary lack of a common, consensual domestic vision for building the future makes it more difficult to attach priority to strengthening Brazilian ecosystems to effectively seize opportunities afforded by disruptive innovations and deflect the risks of obsolescence and consequent loss of industry competitiveness. For this reason, a comprehensive, long-term national innovation policy should be devised to build ST&I foundations and mobilize companies and research institutions to set up creative and dynamic ESs in line with the competitive potential of Brazilian industry. This task requires persistence, patience, ambition, and vision for the future.

Despite the heterogeneity of Brazilian innovation ecosystems, disruptive technologies offer our industry opportunities to improve its insertion in GVCs, strengthening and recovering positions on the world map of industrial production. The initiatives of Brazilian companies and public policies to exploit the new business opportunities afforded by reorganizing GVCs should be agile to prevent them from disappearing or being seized by competitors. This requires the ability to harness their own resources and develop alliances with other companies and institutions with complementary skills to address the risks and costs of innovation. In short, it requires strengthening existing ESs and developing new innovation networks.

The impact of disruptive technologies on integrated processing industries is relevant and affords opportunities for strengthening and improving the insertion of Brazilian companies in GVCs. In these competitive sectors, additional cost reductions and efficiency gains can be achieved with relatively low investments compared to the capital invested and to the quality gains in products. Brazilian companies must keep up with the new technological frontier set by companies producing disruptive innovations.

Brazilian producers enjoy consolidated competitive positions in upstream links of GVCs, in the production of basic inputs, in oil exploration and production, and in agricultural commodities, fibers, and inputs of agricultural/forestry origin. Disruptive innovations can increase the competitive advantages of these Brazilian producers in the global market in a context in which efficiency and environmental sustainability have gained importance as factors of competitiveness in those activities. The ecosystems linked to the activities of these producers can evolve with the new technological frontier set by disruptive technologies and preserve Brazil's competitive position in these GVCs.

The insertion of Brazilian industry in the manufacturing activities that characterize the downstream links of GVCs is more heterogeneous. Brazilian manufacturers enjoy solid positions in some global consumption and capital goods niches; but in other cases their competitiveness is insufficient for them to enjoy a more favorable insertion in those niches. Brazilian industry has lost positions to China and other Asian countries in the production of capital goods, ICT goods, and consumer goods and their components.

The new technologies relativize the advantages of cheap labor and of scale that sustain the competitiveness of some of Brazil's competitors, as they intensify the automation and customization potential of products. On the other hand, they intensify the use of capital, which is expensive in Brazil, and require capacity to use digital technologies and the adoption of organizational innovations and new business models. Notwithstanding these challenges, gaining productivity gains, developing innovative products, and taking advantage of opportunities derived from customization needs could open up exciting opportunities to recover positions in the world ranking.

The main challenge for less competitive manufacturing segments in Brazil is to overcome the limits of a very lagged and unequal dissemination of new technologies among enterprises. With extremely unequal capacities and competencies to move to a new generation of technologies, large capital goods enterprises and foreign or domestic subsidiaries coexist with small and medium-sized technology-based companies and with less sophisticated manufacturers. Thus, gaining and even maintaining market positions depend on the reach and speed at which new technologies are learned and absorbed by companies other than those belonging to the group of leading companies, so that productivity gains can spread more broadly among manufacturers at large. As a matter of fact, this is a common challenge facing many countries in their efforts to strengthen the engineering and R&D capacity of their small and medium enterprises (SMEs).

It should be noted, however, that there are very competitive segments in the manufacturing industry in which Brazilian manufacturers enjoy leadership positions in GVC niches, such as in those of aeronautics, agricultural equipment, and electric engines. In these cases, Brazilian companies can use the skills they have accumulated to exploit new technologies and evolve with the technological frontier.

By incorporating disruptive innovations, these manufacturers can improve their main competencies, apart from diversifying their operations toward segments being created by these new technologies: in the case of electric motors, by developing electric or hybrid motorization solutions for trucks and buses; in the case of agricultural equipment, by developing new smart and connected equipment items; and in the case of the aeronautical industry, by internalizing the production of components, creating first-tier suppliers or developing differentiated products. In all three cases, Brazil relies on strong and dynamic innovation ecosystems to leverage more innovative business strategies and exploit its accumulated competitiveness.

In short, while on the one hand disruptive technologies increase risks, on the other they provide actual opportunities for strengthening the competitive insertion of Brazilian companies in the market and for recovering positions in GVCs. Convergent and agile public and private initiatives designed to strengthen innovation ecosystems are essential for these opportunities to be actually taken advantage of.

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8

HUMAN RESOURCES AND SKILLS IN THE FACE OF DISRUPTIVE INNOVATIONS

Among disruptive innovations, digitization is particularly far-reaching and have a bearing not only on production processes as a whole, but also on the models adopted by companies to organize their operations in all branches of economic activity. To a large extent, concerns with the diffusion of digital technologies are based on divergent assessments of their quantitative and qualitative impacts on employment and on the skills of the workforce required by new ways of designing, producing, buying and selling products, and managing companies.

8.1 What would be the impacts on skills and qualifications?

In a traditional industrial society, the idea of "professionalization" plays a key role in normalizing the competencies required to solve problems in the realm of manufacturing. As we move toward a digital society, however, professions in their current form may no longer be the best answer to those needs.

On the one hand, a gradual evolution in how we value certain attributes can be observed in the "nature" of labor: (i) emphasis on tasks performed, which may be routine or non-routine, manual, or cognitive tasks; (ii) emphasis on the required knowledge to perform the above-mentioned tasks, which may be tacit or codified, simple, or complex knowledge; (iii) emphasis on competencies developed in the process of working, which would be associated with the practical application of knowledge in solving problems; (iv) emphasis on skills that would be associated with both technical competencies and socio-cognitive capacities, which integrate with each other through learning processes and can be applied flexibly in multiple contexts.

On the other hand, in the realm of labor relations an evolution can also be observed in basic conditioning factors, as they tend toward encompassing from a well-defined framework of "occupations" associated with routine tasks performed in the work environment or with "professions" linked to formal qualifications and stable jobs that outline a "professional career" to flexible employment relationships, which can depart from traditional professions and focus on specific skills, resulting in individualized professional "paths."

As a result of this evolution, the future of labor will necessarily depend on exclusively human cerebral forces associated with the flexibility derived from the ability to process and integrate information of many different kinds and to perform complex tasks, communicating them to other people. From this point of view, employers should focus on creating work that takes advantage of strictly human capacities, such as curiosity, imagination, creativity, and social and emotional intelligence. For this purpose, more than 30% of all new high-pay jobs would be linked to “essentially human” social attributes (LEVY and MURNANE, 2013). The increased diversity of the workforce is likely to increase the demand for more creative labor, particularly for emerging “hybrid” jobs that integrate technical and project management skills, mobilizing competencies associated with various domains of knowledge.

In this new labor scenario, personal success will largely depend on speeding up learning throughout an individual’s career. Historically, a career was defined as a relatively stable and predictable set of capabilities aligned with the needs of an organization and of an industry. However, in this new scenario, instead of relying on employers to shape the nature and progression of their careers, workers will need to take the lead, cultivating a mindset that allows them to “move” between different jobs, always mindful of high-value emerging skills and of the training requirements associated with them.

While the need for technical skills remains strong, the need for people with communication, interpretation, and synthetic thinking skills is on the rise. Meeting this need requires new types of social skills that are seldom developed through formal technical courses in mathematics or engineering, as they are associated with a broader training in written communication, English, history, art, and business. These new social skills are in turn leading to a change from an educational model focused on STEM (Science, Technology, Engineering, and Math) areas into one focused on STEAM areas, which also include general culture and arts education (as indicated by the inclusion of the letter A in the acronym).

Appropriate skills to meet the challenges posed by the advent of digital technologies can only be acquired by restructuring and modernizing school curricula, especially in the fields of computer science, logic, creative thinking, problem solving, project work, and team work. This requires a change in education at all levels, including in formal and non-formal learning mechanisms, as well as new educational models. The need to overcome the traditional “cocoons” of scientific disciplines that characterize most of today’s education is a challenge that must be tackled quickly.

Box 2 – Is a skills revolution underway?

Several studies recurrently mention changes in the labor market associated with the so-called "skills revolution." From this perspective, content skills (which include literacy in digital technologies and active learning), cognitive skills (such as creativity and mathematical reasoning), and process skills (such as capacity for interaction and critical thinking) have become increasingly important elements of the key requirements for many activities. While demand for skills is rapidly evolving at an aggregate level, the changes taking place in skill requirements within families of individual jobs and occupations are even more pronounced.

However, no universal definition of these skills is available. As a result, a common approach has been that of differentiating between three types of "skills" linked to the learning process. The first one refers to applying essential skills to daily tasks, derived from multiple forms of literacy: writing, mathematics, science, ICT, financial, cultural and civic literacy. The second one refers to applying skills to address complex problems and challenges, which include critical thinking, creativity, and the ability to communicate and collaborate. Finally, special mention should be made of "character" skills, which define how agents position themselves in a changing environment and include aspects such as curiosity, capacity of initiative, degree of persistence and adaptability, leadership capacity, and social and cultural awareness.

A report prepared by Deloitte Access Economics (2017) predicts that soft skill-intensive occupations will account for two-thirds of all jobs by 2030 as compared to half of all jobs in 2000 and that the number of jobs in those occupations is likely to increase 2.5 times more than the employment rate in other occupations.

Source: Prepared by the I2027 project team based on Deloitte (2017) and on Levy and Murnane (2013).

8.2 What is the situation in Brazil in terms of education and vocational training?

Given the changes and impacts addressed in international reports on the topic, a critical aspect concerns the challenges posed for vocational training. In Brazil, enrollments in vocational education increased significantly between 2008 and 2015, hitting the mark of over 1.9 million enrollments. However, in the 2015-2017 period, these enrollments decreased by 4.5%. According to the 2017 School Census, enrollments in high school totaled 7,930,384, while in vocational education they totaled 882,392, equivalent to 11.1% of all regular high school students. Of these, 554,319 were enrollments in technical courses integrated into high school and 328,073 referred to enrollments in technical courses concomitant to high school. Although the data from the Basic Education Census reveal an upward trend in enrollments in vocational education as a result of the National Program for Access to Technical Education and Employment (PRONATEC), they need to increase at a faster pace, since in the world scenario Brazil's figures for vocational education are still very far those recorded in most developed countries, especially for vocational education integrated into high school. This is because only 47.7% of those who enroll in vocational education in Brazil do so after completing high school.

Among projections for the evolution of the labor market and its impacts on vocational training, special mention should be made of the estimates developed by SENAI in the *2017-2020 Labor Map*[11], released in 2016. The Map indicates that some 4 million new jobs are likely be created over the 2017-2020 period. The study also points to the existence of more than 13 million professionals to be trained by 2020 in industrial occupations, 7,199,946 of whom in occupations requiring training of up to 200 hours; 3,348,382 in occupations requiring training of more than 200 hours; 1,836,548 in technical training; and 625,448 in higher education.

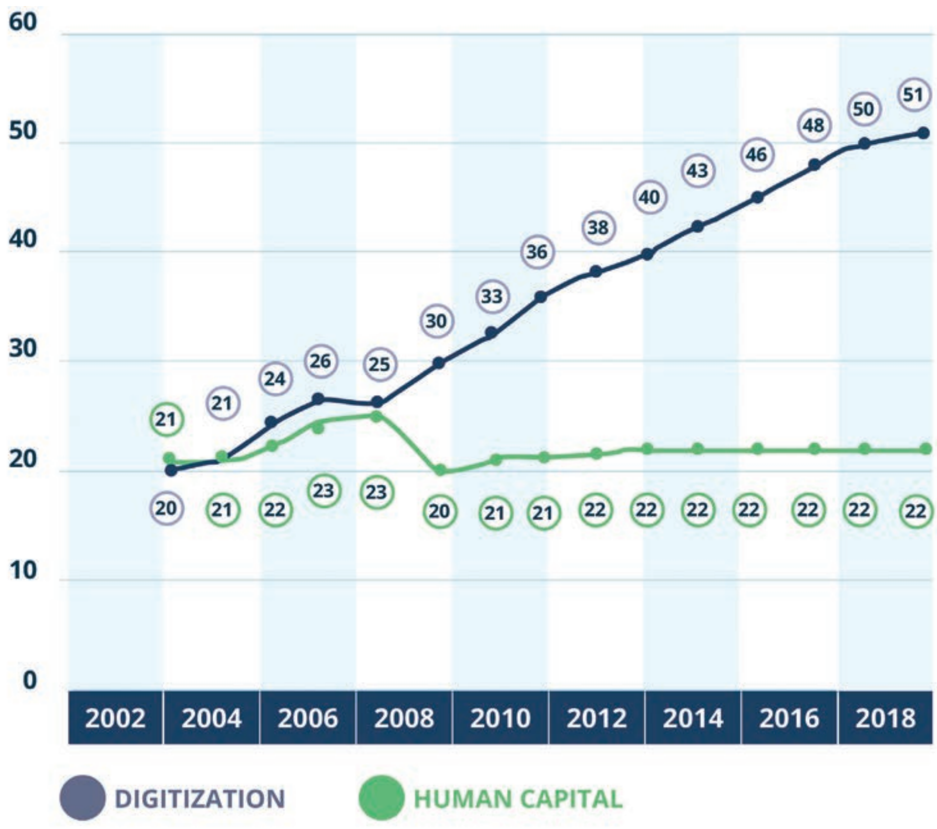
Extending the analysis for higher education, it can be observed that between 2003 and 2016 enrollments in higher education in Brazil doubled, amounting to 8 million students. The gross enrollment rate in higher education, which indicates the number of people enrolled in higher education regardless of age, more than doubled between 2001 and 2015, from 16.5% to 34.6%. However, the net enrollment rate, defined by the enrollment percentage of those at the appropriate age to attend higher education (18-24 years old), is still very low, as only 18.1% of the 22,868,301 young people in the 18-24 bracket are attending higher education in Brazil.

Between 2001 and 2016, there was an increase of 74.8% in the number of higher education institutions in Brazil, 87.7% of which are private universities. Data from the report *Education at a Glance 2016*(OECD, 2016) show that in recent decades access to tertiary education increased remarkably, with about one in every three adults in OECD countries graduating in higher education in 2013, while in Brazil only 15% of the population in the 25-64 age bracket completed this level of education. In addition, 64% of all university degrees earned in Brazil are in the human and social sciences and only 16% in STEM areas, while in countries such as Germany and South Korea, for example, the percentages of graduates in these areas are 37% and 30%, respectively. Despite this gap, there was a 39% increase in enrollments in university technological courses between 2009 and 2016 (from 680,679 to 946,229 enrollments) against a 35.2% increase in total enrollments in higher education in the same period (from 5,594. 021 to 8,048,721 enrollments). It was also observed that enrollments in distance technological courses increased by 102.5% between 2009 and 2015, revealing a faster growth pace than that of enrollments in face-to-face technological courses, which increased by 26.9%.

11 For more information, kindly visit: http://www.portaldaindustria.com.br/agenciacni/noticias/2016/10/industria-precisa-qualificar-13-milhoes-de-trabalhadores-ate-2020/.

Several areas of knowledge taught in higher education will be impacted by the expansion of Industry 4.0. However, engineering-related areas stand out[12]. A study recently published by ECLAC (CIMOLI, 2018) reveals a gap between the increase observed in the digitization rate in Latin American countries and the human capital index, which is a combination of the percentage of people with over 11 years of schooling (more than high school education) and also of the percentage of engineers in the workforce. While digitization increased by 145% between 2004 and 2014, the human capital index rose by only 23% over the same period (Figure 12). Although the study does not individualize data for Brazil, it provides evidence that the situation here is not very different. As a result, some Brazilian universities are already busy readjusting their curricula. The Polytechnic School of the University of São Paulo, for example, intends to create a new course called Complexity Engineering.

Figure 12 – Digitization and human capital index for Latin America, 2004-2014



Source: Prepared by the I2027 project team based on CIMOLI (2018).

12 According to the report *Future of Jobs and Skills* of the World Economic Forum (WEF, 2016), other areas are also expected to increase in importance in the coming years. One of them is that of data analysis, which will help companies assess large amounts of information in support of the management of their business strategies. Robotics coordinators will in turn be responsible for supervising the functioning of robots, working in the preventive maintenance of those machines. Sales representatives are also likely to gain prominence.

The issue of graduating engineers in Brazil generated great controversy years ago, when some analysts pointed out the important role played by engineering in innovation activities and the fact that Brazil ranks extremely low in terms of percentage of engineers per population regardless of the group of countries included in the ranking. However, recent developments in the process of graduating engineers in Brazil have relativized this controversy. In particular, the significant increase observed in the number of enrollments in engineering courses, especially after 2009, alleviated this problem, even though, on the other hand, other problems emerged, notably problems associated with the need for placing and requalifying engineers in a troubled context due to the impacts of a persistent macroeconomic crisis.

In fact, driven by the demand for qualified professionals, by the positive response of the education sector, and by the adoption of funding policies for higher education, enrollments in engineering courses soared between 2004 and 2008 at an average rate of 9.2% a year, a figure very close to that of the growth rate of graduates from engineering courses. Over the following seven years, enrollments in engineering courses increased to a significant 14.6% per year, while the growth rate of graduates was slightly lower as a result of an increase in the dropout rate, even though it remained at double digits. At the same time, however, the average pace of GDP growth declined sharply, leading to a three-year economic slowdown.

Thus, while in 2001 civil engineering graduates accounted for only 1.4% of the total number of graduates, in 2015 they accounted for 2.9% of them. Graduates in other engineering areas, who at one point accounted for 3.7% of all graduates from engineering courses, account for 7.0% today in turn. In 15 years, the sum of these percentages has doubled. The evolution observed in the percentage of new entrants is even more significant: enrollments in all engineering-related courses, which accounted for 6.3% of all new enrollments in 2001, hit the mark of 15.5% in 2015.

However, despite this increase, problems persist: even though there is no firm demand currently for the 100,000 graduate engineers available in Brazil today, our figures remain low in structural terms in the light of international comparisons. It should also be noted that, especially considering new requirements in terms of qualification resulting from new digital technologies, the profile of graduates and the training of engineers are still not in tune with the new needs brought about by the changes being analyzed here. For this reason, the quality of the learning and professional training may have worsened, while the figures for MSc and PhD graduates in engineering remain modest and worrying, as the percentage of engineers with a PhD degree in Brazil in relation to the total declined from 13.8% in 1996 to 9.6% in 2014 (see Box 3).

Box 3 – Recommendations for training human resources for innovation, with an emphasis on engineering education in Brazil

The study *Recursos Humanos para Inovação* (human resources for innovation), prepared within the framework of the MEI initiative and published in 2016, provided an X-ray of the situation of higher education in Brazil, with an emphasis on engineering careers. The study outlined a set of recommendations, which are summarized in the eleven proposals listed below:

(i) Curricular guidelines should be reviewed for the purpose of promoting interpersonal skills in the field of engineering;

(ii) The regulatory framework and curriculum guidelines should be reviewed to revert the current practice of premature specialization and graduate more general practitioners;

(iii) Learning labs should be created and pilot projects developed for renewing engineering education and supporting pedagogical innovations focused on strengthening creativity;

(iv) Education in science and mathematics education in high school should be strengthened;

(v) National exchanges in engineering education should be expanded;

(vi) Interaction between engineering courses and faculty with the market should be stimulated;

(vii) The extremely academic vision of MSc and PhD programs should be reviewed;

(viii) Dropout rates from engineering courses should be reduced;

(ix) Integration between engineering courses and the manufacturing industry should be increased, encouraging the participation of professionals working in manufacturing companies in defining curricula;

(x) MSc and PhD programs in engineering education should be created;

(xi) Expanding courses for technologists associated with engineering areas should be given priority.

Source: Prepared by I2027 project team based on CNI (2016).

8.3 What are the guidelines of employment and vocational training policies in other countries and what are the lessons for Brazil?

Even in leading countries there is evidence that a substantial portion of investments and policies adopted to support the workforce is being thoroughly rethought in the face of ongoing changes. While policy options vary from country to country, there are indications that all societies will need to address five key needs to manage the rapid transitions being experienced by the workforce, namely:

(i) The need to increase the dynamism of the labor market, stimulating greater mobility and fluidity, as required to manage the difficult transitions ahead, mobilizing platforms of digital talents emerging as a result of the rise of the gig economy, combining workers and companies in the quest for skills and offering them new opportunities for articulation.

(ii) The need to update labor market regulations to ensure that high-quality jobs are preserved and lingering uncertainties about workers' benefits are resolved.

In this regard, there are many regulatory challenges to be tackled. Progress must be made in defining the contractual partners in any employment relationship more precisely; in formalizing contractual clauses designed to protect workers in new employment models; in clarifying the concept of "homeworkers" and their underlying duties and rights; in establishing applicable laws and forums to settle potential disputes between employers and employees; in regulating work carried out on web platforms (including crowdsourcing); in regulating conditions for online self-organization and entrepreneurship; in supporting innovative forms of unionization and collective bargaining for online work.

(iii) The need to revolutionize educational models that were designed for a traditional industrial society and have not changed fundamentally in 100 years, so as to better align them with a rapidly evolving new knowledge economy.

The educational reform is intended to promote the adoption of more creative and dynamic learning arrangements, as well as greater diversity in school systems. This effort is necessary to prepare workers for the broad impacts of the dissemination of digital technologies. With the aim of stimulating lifelong education for professionals, policymakers face the challenge of rethinking education for the purpose of bringing out the creative potential in workers and establishing conditions to help everyone develop their talents more quickly throughout their professional lives. In this case, this is intended to facilitate access to continuing education and training throughout a working career that might span 50 years and comprise many different types of work.

(iv) The need to redefine the scope of and redesign professional training mechanisms with the aim of focusing on the development of workforce skills, including professional retraining arrangements that enable individuals to learn new skills throughout their working lives.

It is a must to institutionalize national lifelong training programs, especially for workers with limited general skills whose occupations are more likely to be replaced by new technologies. In this scenario, national training programs for adults focused on improving general skills and, more specifically, the theoretical, cognitive, and digital skills of workers have become more important. By focusing on general skills, these programs complement, rather than replace, employer-initiated training in practical skills (specific skills for occupations in industry).

(v) The need to provide income support to workers and assist them in the transition process in other ways, including through refresher training, a wide range of policies, including unemployment insurance, public assistance in finding work, and benefits that are preserved as workers move from one job to another - in this case, more permanent policies to supplement income, such as more comprehensive minimum wage policies, universal basic income, or the assurance of wage gains tied to productivity. The study *The Future of Jobs* conducted by the World Economic Forum

(WEF, 2016) points out that providing retraining and social protection to workers whose work might be significantly reduced or fully restructured in terms of tasks is a key requirement. However, changes in the world of labor as a result of increasing contractual flexibility indicate that targeting training and retraining efforts will become more difficult. Therefore, the risk of human capital depletion may increase. This means that new arrangements must be devised to effectively share the burden of (regular) training between individual workers, employers, and government.

The need to redesign active employment policies adapted to a flexible working environment requires governments to devise more innovative forms of intervention. Today, government-funded education is targeted primarily to children and young adults who are not yet employed. In the future, such arrangements need to focus on both employed individuals and job seekers with the aim of improving their employability.

Meeting these objectives will require innovative public-private partnerships involving schools, universities, companies, and training providers. Supporting employability can no longer be a one-off action, as it must involve a set of measures and instruments that may be customized to different stages of working life. Because workers will be more likely to change employers, jobs, sectors, and even countries, their benefits and protection mechanisms must be tailored to individuals rather than to jobs or clear unemployment situations, so as to not to have a negative effect on workers with non-standard jobs.

It is interesting that the digital revolution itself can be instrumental for designing these new forms of action, as access to information to calibrate interventions has become a critical factor. This is because using microdata on professional trajectories may be absolutely necessary to measure work resilience, channel investments, evaluate the return on public intervention, and redirect it to where it is most needed. In this regard, using big data provides an opportunity to track and anticipate gaps in terms of skills, map out inconsistencies and polarization in the labor market, and adjust employers' needs to workers' skills. This technology can also help individuals identify potential career options and education and training needs, as well as income possibilities in the job market. In addition, it may be necessary to modernize and expand job classifications in response to the changes underway.

In the case of developing countries, where professional transition processes tend to be particularly traumatic due to gaps in qualifications and skills and to pressures to absorb an increasing labor force, some particular challenges must be tackled in addition to those addressed in the recommendations above. A major challenge related to the future of jobs in developing countries lies in the fact that the agenda of changes in the labor market and the means described to keep up with and intervene in these changes mainly reflect the reality of developed economies. Just as low income in an economy limits the number of good jobs available, it is also associated with a number of other adverse characteristics of labor markets, including increased job insecurity, limited social protection, and high information costs. Effective policy interventions must recognize these problems and make use of all the tools available, including digital technologies themselves, to address them.

More broadly, the increasing need for skills and abilities point to the need to build an education and training "ecosystem" capable of meeting the needs of workers in terms of acquiring technical knowledge and skills and of steering professional trajectories toward continuous learning. Some important implications can be drawn from this observation: on the one hand, a shift in focus from "training centers" to "learning centers" is necessary; on the other, it is imperative to reorient vocational training toward a long-term horizon.

Finally, in the face of so many challenges and difficulties, the most serious problem lies in the weaknesses of the educational system as a whole and in ensuring jobs for those who complete high school, which constitute the main obstacles for expanding higher education in Brazil. In this regard, it is important to consider that in no country the demand for skilled labor for innovation is restricted to college graduates. In Brazil in particular there is strong demand for and a clear bottleneck in vocational training. Despite the recent increased focus on the part of the Ministry of Education and SENAI on vocational training in some states, gaps in high-school-level technical and vocational training in Brazil are still enormous and require greater attention, including improvements in planning, training actions, and greater focus on certain skills, knowledge areas, and priority regions.

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9

NATIONAL STRATEGIES: COUNTRIES BUILD THEIR FUTURE

9.1 Countries build their future

The global economy has been going through deep changes in competition, production, and consumption patterns in recent decades. Disruptive innovations are restructuring the global production of manufactured goods territorially and organizationally at the same time that production in large global corporations is becoming increasing concentrated and centralized. Faced with the breakthrough of disruptive innovations, several countries adopted large-scale strategies to guide their public policies and mobilize the private sector to strengthen and reposition their economies. These new plans are based on a long-term vision that defines technological development missions.

Although these strategies are selective and focused on certain technology clusters and/or production systems, the scope of these guiding missions is their priority. They are also promoting horizontal measures to mobilize the capabilities of companies, universities, and public agencies and steer them in a specific direction[13]. These strategies address industrial development and innovation not as an end, but rather as a means for achieving ambitious goals: changing not only the industrial system, but society as a whole, tackling major societal challenges - such as population aging, education and employment, health care and quality of life, reduction of regional inequalities, energy security, and climate change.

Brazil has not yet built consensus around a long-term vision and strategy. Opportunities remain open, but risks are piling up: the country must define a long-term strategy urgently. As international benchmarks, this chapter analyzes strategies and programs implemented in selected countries according the effort put into them and to the density of their plans: USA, Germany, China, Japan, United Kingdom, South Korea, and France. Examples of relevant programs implemented in other countries are also presented: Estonia, Sweden, Singapore, and Ireland. The objective is to analyze how each country defined its mission-oriented strategic agenda, how this agenda is being implemented, the focus of its main initiatives, and what lessons Brazil can learn from them.

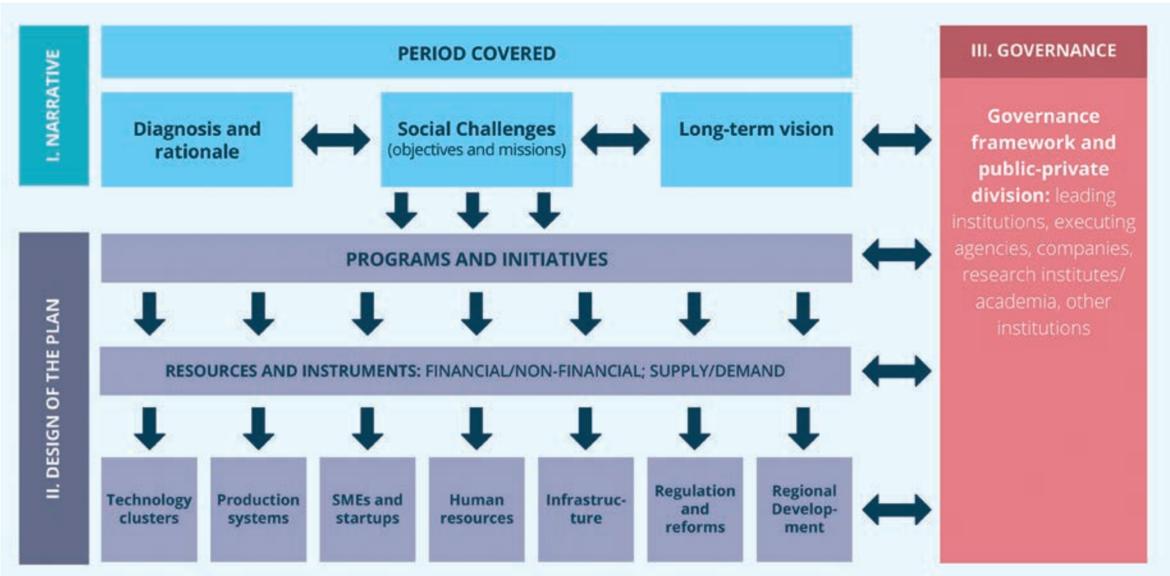
13 Horizontal policies address relevant challenges such as training skilled labor and small and medium-sized enterprises, providing key externalities in the form of advanced laboratory networks and technological assistance programs. Vertical policies for technology clusters or specific sectoral aspects foster innovation ecosystems made up of collaborative business networks, startups, universities, and public agencies working together to achieve specific goals.

9.2 From diagnosis to building visions and implementing strategies

The analysis of national strategies is based on an analytical framework (Figure 13) divided into three dimensions:

- **Diagnosis and prognosis** - how the strategic plan defined the national geopolitical situation and positioning and the long-term vision of technological development missions (objectives).
- **Design of the plan** - under this heading, priority programs and initiatives are discussed, whether vertical (with a focus on technology clusters or production systems) or horizontal (support to small and medium-sized enterprises - SMEs - and startups, including training of human resources, investment in ST&I infrastructure, promotion of regional development, and establishment of new frameworks and regulatory reforms); as well as available financial resources, their sources, and the main instruments mobilized (both on the supply and demand side and including non-financial instruments).
- **Governance and division between public and private** - under this heading, the governance framework and the bodies involved at the highest levels are analyzed; the coordinating team in charge of addressing priorities, setting strategic directions, and structuring the network of public and private institutions is identified; and the executive agencies and both private agents (companies, professional associations, other private institutions) and public agents (official laboratories, universities, state enterprises) are discussed.

Figure 13 – Analytical framework of national strategies in the face of disruptive innovations



Source: Prepared by the I2027 project team.

9.3 Building the future. First step: challenges, visions, strategies and missions

National strategies to address disruptive innovations create platforms for initiatives and actions to converge with the aim of transforming the economy and society. These are **long-term visions** formally proposed through one or more industrial plans in which investment in innovation is seen as a means for realizing great ambitions and not as an end in itself. They generally recognize that industry (manufacturing) and innovation are key elements to boost economic growth. Recognizing that potentially disruptive technologies create a window of opportunity is what justifies the formal adoption of a strategy designed to improve industry and stimulate innovation.

The strategies are based on a solid diagnosis of the domestic situation in its geopolitical context and are intended to (re)position the economy of each country in the world economy. However, the rationale behind these national strategies involves much more than aspects related to competitiveness alone: innovation is seen and supported as a means for tackling major societal challenges - which is the ultimate goal of the strategies. The main challenges addressed include: environmental and climatic issues, demographic transition (population aging), health care and quality of life, national security and cybersecurity, efficient use of resources, participation of society.

The Chinese vision, whose focus is more restricted to the strategic positioning of Chinese industry in the global economy, stands out as an example of an ambitious long-term vision; as well as the Japanese vision, which represents a strategy for a comprehensive transformation of society; and the British vision, which guides policies designed to address societal challenges.

The Chinese strategy is a direct response to the plans of other countries, such as the German High Tech Strategy and the Advanced Manufacturing Partnership of the US, and is based on development visions for three long-term horizons. In the horizon up to 2025, the idea is turning China into a major industrial power by digitizing industry, mastering technologies in key areas, improving product quality, and increasing resource efficiency; reducing pollution; and promoting greater presence of Chinese companies in the international market and improving their position in global value chains. In the horizon up to 2035, the goal is to raise Chinese industry to an intermediate level among the world's industrial powers through improvements in its innovative capacity, breakthroughs in key areas, improvements in its overall competitiveness, leadership in some areas, and comprehensive industrialization. And in the horizon up to 2049, the year of the 100th anniversary of the New China, the plan is to turn China into a leading country among the world's industrial powers in terms of innovation, competitive advantages in large industrial areas, and advanced industrial technologies and systems.

These visions translate into objectives (missions) that can be summarized as follows: "Industry is the topic, improving its quality is the key objective, integrating industry into next-generation IT is the common thread, promoting smart manufacturing is the priority, and meeting demands related to economic and social development and national defense is the goal." The Chinese strategy contemplates four objectives: from "Made in China" to "Created in China"; from "China speed" to "China quality"; from "Chinese products" to "Chinese brands"; and from "big industry" to "strong industry".

The Japanese strategy highlights social and environmental challenges to be tackled both domestically and globally: these challenges range from population aging, which will increase social security costs and reduce the working age population, to the increased occurrence of natural disasters, including heavy rains, and also challenges related to energy and water supply and to infectious diseases. It is a very ambitious strategy, including in terms of increasing R&D spending to 4% of GDP by 2020 (from 3.09% in 2016), and one that involves more than promoting changes in industry and in specific sectors. The S&T policy is presented as the main tool for fostering the creation of a "supersmart society," or as the Japanese refer to it, a "society 5.0." The idea is that of creating an open and global innovation system characterized by greater flexibility and mobility of ideas and people for the purpose of leveraging the importance of Japan as a world leader in ST&I.

The Japanese ambition to become the most more "innovation-friendly" country in the world translates into five objectives (missions): (i) creating a favorable environment for the development of the industry of the future and for social change; (ii) addressing economic and social challenges; (iii) reinforcing the foundations of the innovation system; (iv) establishing a systemic virtuous cycle between human resources, knowledge, and capital for innovation; and (v) promoting deeper ties between S&T and society.

Another clearly mission-oriented case is that of the British strategy, which focuses its industrial and innovation efforts on tackling four main societal challenges. The first one is digital transformation and to address it the strategy was designed to place the UK at the forefront of the data revolution and artificial intelligence. The second one is environmental sustainability, with a view to maximizing the advantages stemming from the global shift toward clean growth for the UK industry. The third one is clean and smart mobility, and the objective here is turning the UK into a world leader in designing the future of mobility. Demographic transition is the fourth one, and the idea is to harness the power of innovation to devise solutions for an aging society.

To address these challenges, the British strategy is anchored in five "ideas of the future" (visions), namely: *ideas* - the United Kingdom as the most innovative economy in the world; *people* - high-quality jobs and higher incomes for all British citizens; *infrastructure* - major improvements in UK infrastructure; *business environment* - the UK as the best place to start and grow a business; and *places* - prosperous communities across the UK.

9.4 Building the future. Second step: plans and programs

In the national strategies analyzed here, comprehensive programs can be identified for each of the technology clusters (vertical programs), particularly: digital technologies (cyberphysical systems, IoT, data analytics, AI, networks, edge computing, augmented reality, quantum computing); additive manufacturing; robotics; nanotechnology and advanced materials; bioeconomics and biotechnology (especially biopharmaceuticals). Vertical programs for specific production systems according to the advantages enjoyed by each country were also identified: health care complex (advanced medical equipment, health care for the elderly); mobility (smart mobility, electric cars, autonomous cars, trains); and energy (mainly renewable energy).

There is also a strong emphasis on cross-cutting, targeted programs designed to complement technological and sectoral programs. Here the main foci are the following ones: concerns about training the workforce; promoting and supporting SMEs and startups; regional development, whether to develop regions lagging behind or to take advantage of or create local advantages; promoting greater cooperation between industry and academia with the aim of turning new knowledge into innovations; and improving the business environment through investments in infrastructure, establishment of technical standards, regulatory frameworks, intellectual property laws and systems.

In terms of resources and instruments, each national strategy tends to set ambitious goals to mobilize public and private funds for ST&I. For example, the United Kingdom, whose investments in R&D in relation to GDP stood at 1.69% in 2016, intends to increase them to 2.4% of GDP by 2027 (IEDI, 2018c; HM GOVERNMENT, 2017). Japan has one of the most ambitious R&D investment targets in relation to GDP - 4% by 2020 (RCCC, 2015; GOVERNMENT OF JAPAN, 2015). In the short term, the funds already secured to implement the national strategies are also considerable: in the US, where US$176.81 billion is the 2018 budget for federal science and technology agencies (EOP, 2016); in Germany, where to a budget of 15.8 billion and 17.6 billion euros of the Ministry of Education and Research in 2016 and 2017, respectively, 1.9 billion euros of the Fraunhofer-Gesellschaft's budget were added and industry took on the commitment to invest 2.5 billion euros in private investment in "Industry 4.0" initiatives (IEDI, 2017a; GT&I, 2014; BMBF, 2014; ACATECH, 2013); in China, where the budget for R&D was US$279 billion in 2017, plus US$22 billion for the National Integrated Circuit Fund and another US$3.2 billion for the Advanced Manufacturing Fund (IEDI, 2018a; STATE COUNCIL, 2015; MERICS, 2016; MIZUHO BANK, 2015a, 2015b).

However, the focus of these strategies shifted from financial instruments with an emphasis on supply to the coordinated use of non-financial instruments, especially co-investments in ecosystems made up of companies, laboratories, networks, and open innovation platforms together with traditional supply-side financial instruments and demand-side instruments (mainly public procurement).

A key concern is making sure that the design of institutions, programs, and initiatives makes it actually possible for research output to be finally implemented in increasingly complex industrial systems. For this purpose, several countries are investing in applied technology centers and pilot manufacturing facilities focused on promoting practical applications of innovations developed in laboratories. In times of budget constraints, countries make an effort to capture value from their investments in science and innovation and to ensure appropriate cost-benefit ratios. In addition, scaling up technology requires the right combinations of tools and resources, such as advanced metrology, real-time monitoring technologies, characterization, analysis and testing technologies, shared databases, and modeling and simulation tools.

In this area, two investment programs for laboratory networks stand out: Manufacturing USA Institutes and Made in China 2025 Innovation Centers (IFM-ECS, 2018). In fact, the main program of the US strategy is one intended to set up a network of Manufacturing USA institutes (IEDI, 2017b; EOP, 2012a, 2012b, 2014). Apart from creating research laboratories, this network will comprise centers for promoting joint public-private actions to generate and disseminate knowledge with a dual function: promoting education/training and providing shared infrastructure, particularly for SMEs. Next, a list will be presented of 14 institutes already in operation of 45 to be implemented over the next ten years with specific technological foci and Federal Government investments of US$600 million, combined with more than US$1.3 billion in private investments (for each two dollars of public investment, two dollars of private investment):

- **AFFOA (Advanced Functional Fabrics of America**) - advanced textile materials; technologies - materials, processing of materials, sensors and electronics.
- **AIMPhotonics** (American Institute for Manufacturing Integrated Photonics) - integrated photonic solutions for both defense and civil applications; technologies - sensors, optics and photonics, electronics.
- America Makes - Additive manufacturing and 3D printing; technologies - materials, processing of materials, light materials.
- **ARM** (Advanced Robotics Manufacturing) - commercial development of robotics technology; technologies - artificial intelligence, sensors, modeling and simulation, automation, electronics, advanced materials.
- **BioFab USA** - cell and tissue cultures for existing industries and new ones; technologies - biomanufacturing, robotics, advanced materials.
- **CESMII** (Clean Energy Smart Manufacturing Innovation Institute) - smart manufacturing; technologies - sensors, modeling and simulation, digital technologies.
- **DMDII** (The Digital Manufacturing and Design Innovation Institute) - dissemination of digital technologies in industrial plants; technologies - design, automation, digital technologies.
- **IACMI** (The Institute for Advanced Composites Manufacturing Innovation) - low-cost and highly energy-efficient manufacturing of advanced polymer composites for vehicles, wind turbines, and compressed gas storage; technologies - advanced materials, processing of materials, light materials.

- **LIFT** (Lightweight Innovations for Tomorrow) - lightweight innovations; technologies - modeling and simulation, metrology, design, advanced light materials, processing of materials.
- **NetFlex** - hybrid electronic technologies (printed and advanced semiconductor components) and flexible electronic technologies (built on flexible materials); technologies - sensors, digital technologies, electronics.
- **NIIMBL** (The National Institute for Innovation in Manufacturing Biopharmaceuticals) - flexible and efficient manufacturing of biopharmaceuticals; technologies - metrology, biotechnology, advanced materials, processing of materials.
- **Power America** - speeding up the adoption of advanced semiconductor components; technologies - electronics, advanced materials.
- **RAPID** (Rapid Advancement in Process Intensification Deployment Institute) - molecular-level technologies for saving energy; technologies - chemical processing, processing of materials.
- **REMADE** (Reducing Embodied - energy and Decreasing Emissions) - technologies to reduce the energy intensity and use of industry materials, reducing carbon emissions; technologies - recycling, reuse, sustainable manufacturing.

The National Centers for Innovation in Manufacturing promoted by the Made in China 2025 strategy are intended to solve information, coordination, and network failures with the aim of strengthening the role of industry in setting research and development priorities (IEDI, 2018a; STATE COUNCIL, 2015; MERICS, 2016; MIZUHO BANK, 2015a, 2015b). In contrast to similar centers set up in developed countries, a key feature of the Made in China 2025 innovation centers lies in their declared goal of helping modernize the Chinese manufacturing industry from "Made in China" to "Designed in China." They intend to do this by paying attention to the scaling up of production, focusing on building a critical mass of multidisciplinary R&D resources to speed up the industrialization of important generic industrial technologies.

Efforts to address challenges related to engineering R&D relevant to industry are characterized by a focus on building stronger links and alliances between universities, companies, and public research institutes. For this reason, these centers are intended to play a key networking role among the different players of the innovation system. In addition, special attention is paid to local and regional contexts with the aim of promoting "differentiated development" supported by an active effort by national and regional authorities to ensure that private companies play a leading role in developing these centers.

The Made in China innovation centers are expected to promote technology and innovation in areas such as next-generation ICT, smart manufacturing, new materials, additives and pharmaceuticals, among others. The first National Center for Industrial Innovation, established in 2016, was the National Center for Innovation in Electric Batteries. Other centers already established or approved are the following ones: the National Center for

Technological Innovation for High-Speed Trains (approved in 2016); National Center for Additive Manufacturing Innovation (established in 2017); the Changshu Innovation Center for Green and Smart Manufacturing (established in 2017); the National Center for Innovation in Information Photoelectronics (approved in 2017); the National Center for Innovation for New Energy Vehicles (approved in 2018); and the Henan Agricultural Machinery Innovation Center (approved in 2018).

On the one hand, the US and Chinese programs for investments in laboratory networks are vertical in nature, as they identify and select specific technologies to be developed; on the other hand, the characteristics of the open innovation process of these networks lend them a horizontal character as well.

9.5 Building the future. Third step: implementing actions - three examples

In all the national initiatives reviewed here, some recurrent topics (IFM-ECS, 2018) are worthy of special attention: support for and promotion of small and medium-sized enterprises (SMEs) and startups; investment in training and (re)training of human resources; promotion of productive and innovative ecosystems; regional development; and reforms/regulations. Three of them will be analyzed below.

9.5.1 Support for and promotion of SMEs and startups

Many small and medium-sized companies are unable to seize the opportunities offered by new technologies, even when these technologies are readily available in the market. Building innovative SME capabilities requires decentralized facilities to reach companies across the country. It also requires a range of support services, including soft support (non-financial instruments) and hard support (financial resources). Here, government-supported information dissemination mechanisms can play a key role in providing information on specific technologies.

Three programs[14] stand out (IFM-ECS, 2018): the Hollings Manufacturing Extension Partnership (MEP), in the United States; and two programs in Singapore: the Singapore Institute of Manufacturing Technologies (SIMTech) and SPRING's Innovation & Capability Voucher (ICV). MEP is a successor to the Manufacturing Technology Centers Program developed in 1989, in response to the recognition of the US's declining position vis-à-vis Japan. The MEP network provides technical expertise to small manufacturers, strengthens supply capabilities, and fosters collaboration among suppliers. MEP has nearly 600 offices and centers in all 50 U.S. states and Puerto Rico. Although MEP is

14 The South Korean strategy is largely based on the promotion of innovation in SMEs (IEDI, 2018b, MSIT, 2017, 2014). Although the country has fewer resources than the others, the ambition to transform the South Korean industrial park is huge: 30,000 smart factories by 2025. The country's first programs for SMEs already seem to be yielding promising results: a 25% increase in the productivity of modernized plants; a 27% decrease in defect rate; and a perceived increase in the propensity of supported companies to innovate.

part of the National Institute of Standards and Technology (NIST), its funding model is a public-private partnership. Its partners include nonprofits, state government agencies, and universities. More than 1,200 experts work with manufacturers to help them improve their processes and identify opportunities to adopt new technologies or launch new products on the market; and MEP provided assistance to more than 25,000 manufacturers in fiscal year 2016.

MEP services include improving suppliers and optimizing the supply chain, tracking suppliers and business-to-business networks, and accelerating the supply chain technology. Examples of support provided include product development and prototyping, technology-driven market intelligence, and workforce development. In this sense, the program focuses mainly on introducing knowledge into new applications, with some emphasis on knowledge generation and diffusion.

Based on the most recent data, the return on investment generated by the programs is remarkable. In 2016, the MEP network aided 11.7% manufacturing SMEs in the U.S., and for every dollar of federal investment, the MEP national network estimates that US$17.9 are generated in new sales for manufacturers and US$27.00 are generated in new client investments, which translates into US$2.3 billion in new sales annually. In addition, for every dollar of federal investment, MEP creates or retains one manufacturing job.

Emerging technologies involve opportunities to increase the company's productivity and competitiveness. However, the absorptive capacity is not homogeneous across all company sectors and sizes. SMEs tend to face different constraints that may prevent them from making the most of the opportunities offered by new technologies. Singapore's experience with innovation and capability vouchers is a good example of how to reduce barriers of access to knowledge and technology.

The Innovation & Capability Voucher (ICV) is an initiative managed by SPRING Singapore, an agency within the Singapore Ministry of Trade and Industry. The ICV consists of subsidies for SMEs in the form of SGD5,000 (US$3,800) vouchers to pay for consulting services and technology solutions. The initiative was launched in July 2012, with a budget of SGD32 million (US$24.2 million) to be spent over a four-year period. Originally, the scheme included only consulting services in innovation, productivity, human resources, and financial management. However, in 2014 the ICV was extended to other categories such as equipment and hardware; technical solutions; professional services; and design and renovation services. This extension also involved additional resources worth SDG10 million (US$7.6 million). In 2015, 19,500 companies used the ICV scheme.

ICV is a fully government-funded program, but its implementation relies on service providers. These providers are prequalified to ensure quality consulting services. Universities and research centers are among prequalified service providers. The ICV scheme enables monitoring projects, encouraging the commitment of SMEs and limiting the "excessive use" of the vouchers by the same companies. Another relevant feature of

ICV is its flexibility to adapt to changes in the training needs of SMEs, as shown by the 2014 extension, which involved not only additional resources but also a broader scope to cover technological solutions.

The Singapore Institute of Manufacturing Technology (SIMTech), in turn, is a research institute within the Agency for Science, Technology and Research (A*STAR). SIMTech was established in 1993 as the first A*STAR Science and Engineering research institute. The institute works with more than 1,300 companies (multinationals, local companies, SMEs, and startups) in industrial and service projects. Several of these companies have become SIMTech's long-term partners in technology development.

The objectives of the institutes are to increase the human capital base, generate, apply and market R&D and enrich the industrial capital base. In this regard, the institute is actively engaged in programs in which resources and expertise in technology are shared with groups of industrial and research partners, and the technology is licensed to local companies and multinational corporations. Since its inception in 1993, SIMTech has supported more than 5,300 projects involving more than 1,300 companies.

SIMTech comprises four research and innovation centers: Manufacturing Productivity Technology Center (MPTC), Precision Engineering Center of Innovation (PE COI), Sustainable Manufacturing Center (SMC), and Emerging Applications Center (EAC). In addition to R&D and innovation, SIMTech supports consortium projects, technology licensing, capacity upgrades, and roadmapping. More than 60% of the companies supported by SIMTech are SMEs.

9.5.2 Investment in training and (re)training

Advances in new technologies require workers with new multidisciplinary competencies, combining different types of knowledge and skills. There are different types of collaboration to create and deliver curricula and courses led by industry, especially those specializing in precision engineering. Some approaches are also aimed at replicating state-of-the-art manufacturing facilities to provide the right environment for quality training, in collaboration with industry. There are also programs that establish vocational schools to provide training in emerging technologies tailored to the specific needs of SMEs.

In the area of human resources, three programs (IFM-ECS, 2018) stand out: Skills Future Singapore Programs at SIMTech, Singapore; NIBRT Programs, Ireland; and KOMP-AD, Denmark.

Emerging technologies are likely to replace highly automated jobs, creating new jobs and related demand for new skills. These trends pose challenges for both employees and employers. Two of Singapore's main agencies involved in disruptive technology training are the Singapore Institute of Manufacturing Technology (SIMTech) and Skills Future Singapore (SSG), a statutory board under the Ministry of Education (MOE).

SIMTech's Knowledge Transfer Office (KTO) provides case study-based training for manufacturing experts, engineers, and managers, as well as for other industry professionals and executives. In October 2016, the Singapore Workforce Development Agency (WDA) was reconstituted into two statutory boards: SkillsFuture Singapore (SSG) and Workforce Singapore (WSG). SSG coordinates the implementation of SkillsFuture initiatives. It is a "national movement" to provide Singaporeans with the skills required by the rapidly changing economy; it is comprised of various initiatives related to technical skills, skills upgrading, upgrading, or career upgrading or conversion. Several of these programs are implemented in collaboration with WSG. WSG's efforts are focused on helping workers meet their career aspirations and secure quality jobs at different stages of life.

SSG is an example of a policy designed in response to those emerging trends. It provides a comprehensive strategy for skills development, including awareness, mentoring, and digital skills training for different career stages. One of the key features of SSG is its focus on people's careers and not just on industry demands - a focus derived from the approach previously followed by the Workforce Development Agency. Another relevant SSG strategy is the inclusion of the CT skills conversion course. SSG has developed synergies with different player such as SIMTech, in the case of the Manufacturing R& D Certificate Program and the Infocomm Media Development Authority, in the case of TeSA. These synergies show the importance of having agencies such as Skills Future Singapore and Workforce Singapore, which work in a cross-cutting manner to develop the country's workforce.

The case of SIMTech's KTO, on the other hand, shows a long-term, R&D-based approach. SIMTech has collaborated with industry for more than two decades and, as a result, the curricula of the courses offered by the institute are industry-led and mainly specialized in precision engineering.

Inaugurated in 2011, the National Institute for Bioprocessing Research and Training (NIBRT) is a global bioprocessing training and research center. NIBRT facilities in Dublin, Ireland (6,500 m^2) were built to closely replicate a state-of-the-art bioprocessing facility that allows trainees to experience skills-based practical training. NIBRT provides a "one stop shop" for the training requirements of the bioprocessing industry. It is based on a partnership between University College Dublin, Trinity College Dublin, Dublin City University, and the Institute of Technology, Sligo. It was funded primarily by the Irish government through Ireland's inward investment promotion agency IDA Ireland (Industrial Development Agency).

The Irish experience with NIBRT is a success story of skills development in collaboration with industry. It was funded as part of a broader strategy to attract foreign investment to the pharmaceutical industry. NIBRT's main strategy was to replicate state-of-the-art manufacturing facilities to provide the right environment for quality training. This effort is supported by the institute's R&D activities, which includes contractual research. In addition, NIBRT has been working as an umbrella organization, bringing together in one place the research and training experience of different Irish institutions.

Successful collaboration with industry has enabled NIBRT to maintain a strong track record of graduates employed in the pharmaceutical industry. In addition to this prestige, Springboard's free courses have also proven to be an effective talent attraction strategy. Partnerships with higher education institutes and professional associations have also been crucial in meeting industry skills demands.

The educational program Competence Track for Automation and Digitization in SMEs (KOMP-AD) was initiated in 2013 and finalized in 2015. Introduced by the Ministry of Commerce and the Danish Growth Board in response to declining Danish competitiveness, KOMP-AD addressed the lack of knowledge and practical competencies in the field of automation and digitization. Created as a national consortium, KOMP-AD established itself as a network of 30 partners, including Danish vocational schools and colleges, SMEs, business associations, and public actors under business support. The long experience of Danish vocational schools in involving SMEs in practical learning in the workplace facilitated digitization and automation efforts. In addition, business schools also contributed by developing new practical learning models, with the participation of sectoral associations and business promoters.

The total budget for this initiative was EUR 5.7 million (US$7 million), of which half was funded by the EU Social Fund. The main program impact indicators show that 72% of participating companies (total of 250 companies from January 2013 to June 2015) experienced some improvement in productivity; 41% experienced an increase in revenue; and 55% experienced an increase in profits.

The KOMP-AD case is an example of a bespoke program designed to increase absorptive capacity among SMEs. The program focused on digitization and automation. This Danish experience shows how vocational schools can offer training on emerging technologies tailored to the specific needs of SMEs. The evaluation of the program showed evidence of a positive impact, especially on the productivity of companies. In addition, the evaluation found a great deal of untapped potential to increase the levels of digitization and automation of Danish SMEs. Approximately half of the participating companies indicated that they would not have attended any skills development course had not had the opportunity to participate in KOMP-AD.

9.5.3 Promotion of productive and innovative ecosystems

Here, special mention should be made of the efforts to engage more companies in the R&D network by creating multidisciplinary teams and securing aligned investments in technological areas that depend on each other and ensuring critical mass. Research associations play a prominent role in bringing together groups of companies to identify, with the support of experts, common needs (including in terms of public policy bottlenecks) as well as areas of opportunity to be explored.

Two German programs of this kind are noteworthy (see also the U.S. and China laboratory networks presented earlier) (IFM-ECS, 2018): Central Innovation Program for SMEs (ZIM) and German Federation of Industrial Research Association (AiF). The Central Innovation Program for SMEs (ZIM) was launched in 2008 to support SMEs in developing new products or improving existing products, processes or technical services. AiF Projekt GmbH manages ZIM on behalf of the Federal Ministry for Economic Affairs and Energy (BMWi). ZIM participates in IraSME, a network of ministries and funding agencies that manages national and regional funding programs for cooperative research projects among SMEs. The initiative funds R&D projects, cooperation networks, and market launch of R&D project results.

ZIM funding is available to German SMEs in all technologies and sectors (up to 499 employees and turnover of less than EUR50 million/year or a total balance sheet not exceeding EUR43 million). The annual budget is over EUR500 million (US$612.2 million). ZIM has signed bilateral financing agreements with Alberta (Canada), Brazil[15], Finland, France, Japan, Singapore, South Korea, Sweden, Taiwan, and Vietnam.

Some of the estimated results of the program are: from 2012 to 2015, Zim-funded companies experienced an average increase in sales of almost 12%, while the number of employees increased by 15%; more than half of the projects were carried out by small companies; approximately 70% of companies succeeded in increasing their sales from 2012 to 2015; an average of 0.5 jobs was created and 2.4 jobs were retained; almost 90% of companies intensified their cooperation with other companies.

The second outstanding German initiative is the German Federation of Industrial Research Association (AiF), Germany's leading national organization for the promotion of applied research in SMEs. AiF and its research associations seek to provide comprehensive R&D support to help SMEs meet the challenges of technological change. AiF's innovation network consists of 100 industrial research associations representing 50,000 companies, mainly small and medium-sized enterprises. Each research association represents a particular business sector, from specific branches of the economy or technology fields.

Since its foundation, AiF has already disbursed more than EUR10 billion (US$12.2 billion) in funding for more than 200,000 SME research projects. In 2016 alone, EUR532 million (US$650 million) were disbursed. The main technological fields financed this year are nanotechnology, production technologies, materials technologies, electrical engineering, and health and medical technology research.

One of AiF's main achievements was to become an umbrella organization: having multiple research associations under one roof and promoting networking activities

15 On August 20, 2015, the government of Brazil (Secretariat of Innovation and New Business of the Ministry of Industry, Foreign Trade and Services - MDIC) and Germany signed a Joint Declaration of Intention on bilateral cooperation in research, development and innovation.The second and most recent call for proposals for R&D projects between German and Brazilian companies was published on November 28, 2017. According to the general guidelines of ZIM cooperation projects, German partners are funded by the ZIM program itself. Funding for Brazilian partners is provided by the following Brazilian institutions: BNDES, EMBRAPII and FAP.

can reduce the burden and uncertainty of participating in R&D activities. The AiF case is also an example of how nongovernmental organizations can play an important role in coordinating industry and academia interests, thus facilitating the translation of knowledge and technology into marketed solutions. In addition, AiF's proven experience in working with SMEs, coupled with transparency in its organization has motivated the government to appoint the association to coordinate and implement publicly-funded programs since the late 1970s.

9.6 Necessary and essential conditions: political priority, public-private concertation

Coordination and governance initiatives prioritize the establishment of national cooperation and communication platforms, which stimulate collaboration among all players in the innovation system. These initiatives are based on the common national vision around new technologies through national strategic programs.

In many cases, the control team is made up of representatives not only of the government, but of industry and academia as well. At the governance level, plans are implemented primarily through public-private partnerships, in recognition of the need to strengthen both the public and private sectors (strong State and market).

Under the U.S. national strategy, governance takes place at the federal executive level (EOP, 2012a, 2012b, 2014, 2016): the strategy is led by the National Science and Technology Council, an executive body directly under the Office of the President of the United States. The Council is composed of the president and director of the Office of Science and Technology Policy, the vice president of the United States, secretaries and heads of agencies with significant scientific and technological responsibilities, and other White House officials when necessary. Under the NSTC are the Interagency Working Group on Advanced Manufacturing (IAM) and the Subcommittee on Advanced Manufacturing (SAM), which brings together 13 federal agencies.

A program with noteworthy governance in the U.S. strategy is the National Nanotechnology Initiative (NNI), an R&D program involving the nanotechnology-related activities of 20 U.S. departments and independent agencies. Each of these departments has priority or secondary foci in related areas such as: nanoscale science of fundamental processes and phenomena; development of nanomaterials; nanoscale systems and artifacts; research in instrumentation, metrology and standardization; nanomanufacturing; creation of large research laboratories; environment, health and safety; and social and civil education.

The initiative has recently promoted the creation of the National Nanomanufacturing Network (NNN), an alliance between academia, government and industry for cooperation and advancement of nanomanufacturing in the country. The goal of the network is to be a catalyst for progress in nanomanufacturing in the U.S., and its role will be to promote workshops, roadmapping, interinstitutional collaboration, technology transition, testbeds, and information exchange services. It operates as a free access network of centers, leaders, specialists, and interest groups in nanomanufacturing research, development and education.

These initiatives are: (i) communication, cooperation and collaboration platforms for these federal agencies; and (ii) structures for sharing objectives, priorities, and strategies to help participating agencies tap the resources of all partners. NNI has an interesting governance structure, which is coordinated at the level of the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget(OMB), together with the National Nanotechnology Advisory Panel, which has become part of the President's Council of Advisors on Science and Technology (PCAST), with 18 members (plus the OSTP director) from industry and academia. It should be noted that President Donald Trump has not yet appointed the members of PCAST, nor the director of OSTP.

The French strategy also presents interesting governance mechanisms (IEDI, 2017b and LE GOUVERNMENT, 2016, 2015). The strategy is mission-oriented, focusing on the identification of nine technological themes aimed at the reindustrialization of the country (La Nouvelle France Industrielle – New Industrial France plan), on the promotion of high technology sectors (Industrie du Futur plan) and on the search for concrete responses to the challenges of French society. These challenges include: (i) data economy; (ii) smart objects; (iii) digital trust; (iv) smart food production; (v) new resources; (vi) sustainable cities; (vii) eco-mobility; (viii) transport of tomorrow; and (ix) medicine of the future. However, these themes are broken down into lines of action at the sectoral level: the French strategy creates 34 sectoral plans led by specialists in each area, who are the organizers of collective work and collaborative projects. These managers are responsible for reporting on the progress of their plan and preparing action roadmaps, which are validated by a steering committee that brings together public and private actors under the authority of the Prime Minister (the so-called "Alliance for the Industry of the Future"). Governance incorporates a project-based interdepartmental modus operandi, in which the public and private sectors meet in a co-construction approach.

An example of governance at the implementing agency level comes from the Swedish Government Innovation Agency, VINNOVA (IFM-ECS, 2018). Established in 2001, its mission is to strengthen Sweden's innovation and competitiveness capacity by encouraging collaboration between different actors in the innovation system. The Agency facilitates the development and implementation of joint research and the development projects between companies, universities, colleges, research centers, the public sector, and civil society, both in Sweden and internationally. VINNOVA has offices in Stockholm, Brussels and Silicon Valley. The Agency reports to the Ministry of Industry and the National Contact Authority of the EU Framework Program for Research and Innovation.

VINNOVA has a large portfolio of instruments and programs focused on the following fields: circular and bio-based economy; industry and materials; smart cities; life science;

and travel and transport. The focus of VINNOVA initiatives includes supporting incubators, promoting collaboration, developing long-term strategic programs, and financing innovation projects in the public and private sectors. Overall, approximately 45% of the agency's budget goes to universities and 30% to companies. Almost 60% of the funding earmarked for companies goes to SMEs and several of VINNOVA's funding programs are targeted at this category of companies.

VINNOVA's activities cover a wide range of functions related to the coordination and establishment of a common national vision around new technologies. Its main instruments to ensure the coordination and alignment of efforts are the Strategic Innovation programs. The actors involved in each field have established a common vision and defined needs and strategies to develop an innovation area. The starting point for their agendas was to address major societal challenges, create growth and strengthen Sweden's competitiveness.

In 2017 there were 17 Strategic Innovation programs in areas such as mobility, IoT, basic metals, medical technology and health care, manufacturing automation and digitization, sustainable use of resources, and social housing. In that year, VINNOVA invested SEK3.1 billion (US$375.6 million) to promote innovation and supported 3,834 projects.

9.7 Inspirations for Brazil

Unlike advanced economies, Brazil has not yet developed a comprehensive national advanced strategy for large-scale manufacturing. Nevertheless, the window of opportunity created by the current technological revolution remains open. However, seizing it requires the urgent development of an ambitious national strategy that addresses the structural deficiencies of our innovation ecosystems and thus advances the Brazilian socio-economic development project (MARSH, 2017, NOLAN, 2017

This chapter has identified recurrent themes of national strategies in the face of disruptive innovations and underlying programs of selected countries, which translate into some lessons for the development of a Brazilian national strategy[16].

- **Long-term vision** - national strategies are structured around a common (consensual) national vision to guide the actions of industry, government and academia, which unfold into missions to which the various policies and strategic actions are oriented. In these visions, innovation is a means to achieve great ambitions and solve societal challenges.
- **Vertical programs** - in the national strategies analyzed, large programs can be identified around each of the technology clusters, as well as programs for specific

16 A decade and a half of industrial policy and innovation plans in Brazil, with their hits and misses, have resulted in action programs (public and private initiatives) and institutional structures that can be used in a Brazilian national strategy, as will be discussed in the next chapter.

production systems - both types of vertical programs take into account a diagnosis of the advantages and vocations of each country.

- **Horizontal programs** - in these strategies there is also a strong emphasis on cross-cutting programs, which are complementary to vertical programs, be they technological or sectoral.
- **Resources and instruments** - national strategies set ambitious targets for the mobilization of public and private financial resources for ST&I (in absolute terms and as a percentage of GDP). However, there is a growing emphasis on the coordinated use of instruments - especially in the coordination of traditional financial instruments of supply and demand (mainly government procurement), often through open innovation initiatives (e.g. laboratory networks).
- **Small and medium-sized enterprises and startups** - national strategies show the fundamental importance of considering, clearly and directly, the specific challenges that SMEs in general and startups in particular face to participate in research and innovation activities.
- **Human resources** - national strategies establish comprehensive skills development programs, including awareness, mentoring and digital skills training for different career stages, focusing on people's careers and not just on industry demands.
- **Ecosystems and collaboration networks** - there is an increasing emphasis on promoting collaboration between companies and research institutions through (often international) R&D networks.
- **Governance** - international experience reveals a strong emphasis on the need to ensure better coordination of government actors, technical knowledge and R&D infrastructure, which is done through specific (new or not) coordination and control mechanisms - committees, councils, associations, secretariats - involving the highest executive level in the country (president, prime minister), who develop, help to implement and evaluate strategic actions.

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10

OVERVIEW OF BRAZILIAN INDUSTRIAL AND SCIENCE, TECHNOLOGY & INNOVATION POLICIES: LEGACY, RECENT INITIATIVES AND CHALLENGES

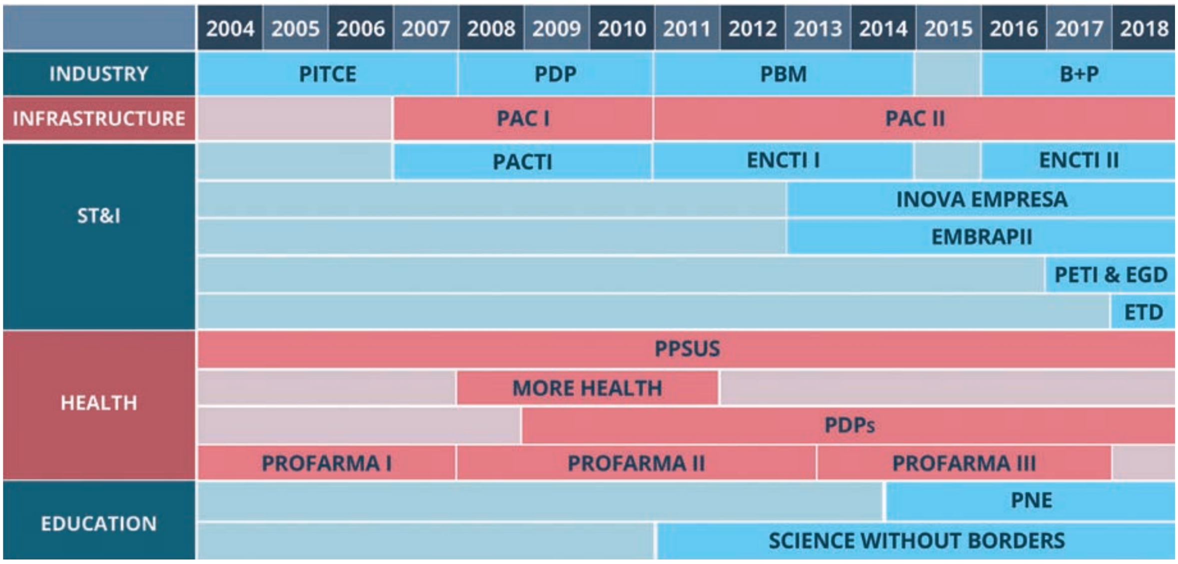
Unlike advanced economies, Brazil has not yet developed a major national innovation strategy. Nevertheless, the window of opportunity created by the disruptive innovations analyzed here remains open. However, seizing it requires the urgent development of an ambitious national strategy that addresses the structural deficiencies of our innovation ecosystems and thus advances the Brazilian socio-economic development project.

This chapter aims to identify, within the Brazilian innovation system, the main public and private actions implemented in the recent past and initiatives currently underway, as well as consolidated institutional structures that could be mobilized for the development and implementation of a Brazilians national strategy in the face of disruptive innovations.

10.1 Industrial and innovation policies: legacies and challenges

Since 2003, Brazil has gone back to developing and implementing strategic plans in different areas (Graph 17). Technological innovations, as well as the diffusion and application of new knowledge, have been seen as key factors for increasing productivity and promoting growth. Horizontal policies to support business innovation, which included tax credits on R&D expenditures and non-reimbursable funds for micro, small and medium-sized enterprises have also become priorities.

Graph 14 – Selected Brazilian strategic plans and programs, 2004-2018, 2004-2018



Source: Prepared by the I2027 project team from Penna and Mazzucato (2016).

By 2014, three industrial policy plans had been implemented:

- **Industrial, Technological and Foreign Trade Policy (PITCE), 2004-2007**: Focused on strengthening innovation activities and supporting selected industrial sectors (capital goods, electronics, pharmaceuticals, and software), its main contributions were the development of a new institutional framework (including legislation) to induce innovation; the establishment of a high-level tripartite forum to promote consensus on industrial strategies and priorities; and the creation of facilitating agencies (such as the Brazilian Industrial Development Agency - ABDI and APEX-Brazil) to promote industrial development and exports.
- **Productive Development Policy (PDP), 2008-2010**: This policy, which was implemented in a context of economic growth and very favorable terms in international trade, focused on fostering investment and sustaining the growth cycle, with a sectoral focus broader than PITCE's. Its institutional arrangement was instrumental in mobilizing countercyclical public action when the great international crisis broke out.
- **Greater Brazil Plan (PBM), 2010-2014:** Marked by the continuation of the international crisis and the fierce competition of imports aggravated by the appreciation of the real, this plan had an even broader sectoral focus than the PDP and emphasized the added value of production chains through innovation; its actions, however, ultimately focused on defending the domestic market and improving systemic conditions for competitiveness.

These plans represent clear continuity - for example, in their focus on innovation and competitiveness - but with adaptations to address different economic challenges to which these policies had to respond. In addition, they symbolized concern and efforts to set explicit goals, mobilize relevant policy tools and interact with the business sector, workers, and academia. It should also be pointed out that these industrial policies have become more integrated into other development policies, such as science and technology, health, education, environment, logistics, energy, defense, local/regional development, and infrastructure. These complementary policies shared objectives and addressed policy instruments in a concerted manner. New instruments were introduced, with emphasis on the use of public purchasing power.

These plans represented a return of active industrial policies, with advances and achievements, as well as an effort to integrate industrial policy with the ST&I policy, so as to encourage companies to incorporate innovation into their production processes as a way to increase their global competitiveness. However, the focus on *short-term* management of the economy - balance of payments, international crisis, "Brazil cost" – hindered the effective implementation of perennial, *long-term* actions.

The most recent federal government's industrial policy - More Productive Brazil (B+P) - represents a reduction in scope and ambition compared to previous plans. Its focuses strictly on increasing productivity by offering technology consulting services to industrial companies that seek to implement "lean manufacturing" techniques to reduce "waste" - overproduction, waiting time, transport, overprocessing, inventory, and defects. The program, which was coordinated by the Ministry of Development, Industry and Foreign Trade (MDIC), used the institutional structure initially implemented by PITCE and later by PBM, and was jointly implemented by SENAI, ABDI and APEX-Brazil, with the support of SEBRAE and BNDES.

Several initiatives designed and implemented by the federal government since 2003 stand out in the list of complementary policies.

In the **infrastructure area**, the highlight is the *Growth Acceleration Program*, which was created in 2007 and started a new phase in 2011, leaving as institutional legacy the resumption of planning and execution of major social, urban, logistics, and energy infrastructure works.

In the **ST&I area**, several initiatives in the last 15 years have helped to structure the Brazilian innovation system. The *Action Plan on Science, Technology and Innovation* (PACTI) and the *National Strategy for Science, Technology and Innovation* (ENCTI, phases I and II) are strategic plans that have consolidated and expanded the national innovation system. Among its legacies are the new legal framework that, among other advances, enabled the regulation and improvement of the Innovation Law, the Law of Good, the Informatics Law, the Biodiversity Law and, as a policy instrument, the Government Procurement Law; institutional and governance strengthening through formal partnerships with state Research Foundations (FAP), the Council of State Secretaries for Science, Technology and Innovation Affairs (CONSECTI), and the National Research Council (CONFAP); the real improvement in laboratory infrastructure; the creation in national and international network of 123 National Institutes of Science and Technology (INCT), in areas considered critical for Brazil; and the implementation of strategic programs for the development of human resources. Also noteworthy is the joint plan of the Studies and Projects Financing

Agency (FINEP) and BNDES called *Inova Empresa* (Box 5), designed to promote solutions to technological challenges in specific ecosystems, which represented a milestone in Brazil's innovation policy due to its systemic character, by supporting interaction between companies, academia and public institutions (multiple ministries, regulatory agencies, official laboratories, state companies).

Currently, two important initiatives are underway in the scope of ST&I: (i) the *Strategic Information Technology Plan* (PETI), 2017-2019, which is in line with the federal government's *Digital Governance Strategy* (EGD). PETI aims to provide ICT excellence solutions to support the policies of the Ministry of Science, Technology, Innovation and Communications (MCTIC) in general and EDG in particular. In turn, EDG is a public sector computerization and digitization strategy; (ii) the *Digital Transformation Strategy* (ETG or E-Digital) aims to "harness the full potential of digital technologies to achieve increased productivity, competitiveness and levels of income and employment throughout the country, with a view to building a free, fair and prosperous society for all". E-Digital is coordinated by MDIC and MCTIC, with contributions from multiple institutions such as the IoT Chamber, EMBRAPII, BNDES, and FINEP among others.

Box 4 – The relative success of the various *Inova Empresa* lines

The *Inova Empresa* plan was Brazil's most ambitious innovation policy and represented a move away from the traditional policies characterized by supply bias, thus illustrating the importance of combining instruments on both the supply and demand side. With a budget of more than R$32 billion, it directed resources to projects for the development of selected technologies in specific ecosystems. For the first time in their history, BNDES and FINEP worked together to finance and enable projects with greater technological and market risks, thus creating a unique channel for obtaining financing and promoting productive partnerships between companies, universities and other research institutions. Inova was inspired by the Plan to Support Innovation in the Sugar-based Energy and Sugar-based Chemical Sectors (PAISS), focused on the development of second generation ethanol (2G) from sugarcane biomass, whose success led to the establishment of other Inova subprograms, each with specific sectoral and technological foci. In total, 12 ministries were involved and demand was almost three times higher than the funds available, which highlights the level of commercial interest in this type of direct and systemic innovation policy. Although many of the subprograms are in progress and present only preliminary results, some can be seen as more successful than others, considering the interest of companies and the quantity and quality of projects proposed in each subprogram.

Penna and Mazzucato (2016) analyzed *Inova Empresa* and identified six types of capabilities required for ecosystems, in order to ensure the internal consistency and effectiveness of the most successful subprograms: (i) scientific-technological capacity; (ii) demand capacity (private or public); (iii) production or entrepreneurial capacity; (iv) coordination capacity on the part of the State; (v) capacity to mobilize policy instruments; and (vi) "analytical" capacity (definition of technological objectives through solid diagnosis and prognosis).

Source: Prepared by the I2027 project team.

In the **education area**, special mention should be made of the creation of the Federal Network of Professional, Scientific and Technological Education in 2008, with 644 campuses in 2016, and the *Science without Borders* program, which took about 100,000 Brazilian students and researchers to 2,912 universities and research centers in 54 countries. The evolution of higher education and scientific research secured Brazil 13th place in scientific publishing in 2015. Currently, the *National Education Strategy* proposes specific targets and programs for technical and vocational education.

In the **health area,** more specifically the Economic and Industrial Health Complex (CEIS) is perhaps the sector that has benefited the most from active industrial and innovation policies. Since 2004, CEIS has established itself through initiatives such as the *SUS Research Program* (PPSUS), *BNDES Profarma* (2004-2017), *More Health* (or Health PAC), and *Partnerships for Productive Development* (PDP), which aimed at increasing access to medicines and health products considered strategic for the Unified Health System (SUS). Also noteworthy are the programs and initiatives to strengthen the productive complex and promote health innovation implemented by the Executive Group of the Industrial Health Complex (GECIS) established in 2008 as a governance body, under the coordination of the Ministry of Health (MS).

The strategic planning experience of the last 15 years, especially in the industrial and innovation area, has left important legacies. First, economic growth and the commodity boom created a relatively comfortable environment in terms of international reserves, which greatly mitigated the short-term focus on the external balance of the Brazilian economy - although the international scenario remains subject to uncertainties. Secondly, related plans and initiatives have created a new institutional framework for public policies, which included not only legal and regulatory frameworks, but also the creation of new agencies and support instruments.

The expansion of credit and public and private investments in infrastructure have enabled reducing systemic costs and economies of scale. The increase in the aggregate investment rate has become a strategic objective by making enabling a significant increase in the potential growth rate of the Brazilian economy. The articulated set of government initiatives have resulted in the possibility of boosting exports, thus expanding both the production scale and productivity, which has contributed to sustainable economic growth.

A severe recession broke out in 2015, due to a shift in macroeconomic policy and the collapse of Congress support for the government. President Dilma Rousseff was formally impeached in mid-2016. Under great economic and political uncertainty in the recent period, fiscal constraints were exacerbated by the sharp drop in tax revenue, leading to a significant decrease in public budgets and investments, and halting all the aforementioned development and ST&I policies. Under pressure from the recession and then from the lack of political predictability, the private sector also significantly reduced its innovation activities. The rise of the new government set in motion a liberalizing policy, focused almost exclusively on restrictive fiscal measures. The late neoliberal agenda and the orthodox fiscal adjustment imposed strong restrictions on investments and loss of budgetary resources, with setbacks in the area of credit and resources used to boost research activities. Against this backdrop, the current scenario is one of major challenges.

10.2 What challenges remain in the scope of industrial and innovation policies?

As pointed out, following the advances of industrial and innovation policies, the development of larger national strategies was interrupted by the outbreak of the economic and political crises. This interruption is in itself challenging and is accompanied by other specific challenges that must necessarily be addressed through a variety of actions and initiatives for the resumption of a national ST&I strategy.

These challenges, often common to the innovation policies of the vast majority of relevant countries (see Chapter 9), can be grouped into eight categories, as detailed below. Initiatives to start addressing each challenge are identified[17], with special emphasis on policies focused on the clusters and production systems covered in the research.

(i) ***Long-term vision***: Unification of the visions of different public agencies through the development of a new long-term strategic vision that defines guiding missions for public and private actions. The initiatives are: (a) the strategic plan of BNDES, *Brazil, developed country*, with a vision for 2035, and EMBRAPA's plan *The Future of the Technological Development of Brazilian Agriculture*, with a vision for 2034; (b) Bill 9163/2017, establishing the governance policy and the long-term national strategy (12 years).

(ii) ***Governance***: High-level governance structure, with decision-making power to coordinate these actions under mission-oriented industrial and innovation policies. To address governance challenges, ongoing initiatives include Decree 9,203/2017 establishing a public governance policy; and the GECIS governance model.

(iii) ***Financing and tax break***: Urgency to overcome the current budget constraints and resource contingency for science, technology and innovation; proposals for the activation of Sectoral Funds and recomposition of the National Fund for Scientific and Technological Development (FNDCT); proposals for strengthening BNDES and its capacity to support entrepreneurial innovation; establishment of effective counterpart contributions in the context of review of tax break schemes. In addressing tax break financing issues, the highlights are: (a) pooling of funds from different agencies such as the *Inova Enterprise* program, and joint calls by FAPs and the National Council for Scientific and Technological Development (CNPq) and the Coordination for the Improvement of Higher Education Personnel (CAPES); (b) the bill converting the FNDCT into a financial fund; (c) the new BNDES operational policy, with resources directed to areas of impact and where it has expertise; and (d) private funds for ST&I (also the proposal of a fund with resources from the "R& D clauses").

17 It should be noted that the initiatives and structures highlighted in each item can serve purposes in multiple areas.

(iv) ***SMEs and startups***: Identify and stimulate SMEs with "smart" growth potential (based on the incorporation or development of innovations); increase SMEs' propensity to innovate; strengthen and promote ecosystems for processes to pair intensive chains in SMEs, including technology centers able to provide assistance, metrology and training services; expand support for startup capitalization. Here the initiatives underway are the *More Productive Brazil* program; and actions of the SENAI and SEBRAE systems focused on SMEs.

(v) ***Human resources***: Need to expand the quantity and quality of engineering programs and graduates in STEM areas; increase efforts for the training and retraining of human resources in companies in face of new technologies; requalification and reallocation of the labor force displaced by disruptive innovations (e.g. by AI). To address human resources-related challenges, the following initiatives are underway: (a) calls from the *Inova Talents, Inova Global, Inova Tec* (IEL-CNPq) programs; (b) joint calls for internship awards in EMBRAPII accredited laboratories (EMBRAPII-CNPq-CAPES); (c) 11 SENAI courses for training in advanced manufacturing technologies; and (d) Federal Network of Vocational, Scientific and Technological Education.

(vi) ***Infrastructure***: Need for investments to overcome the weakness, technological obsolescence and inadequacy of the physical telecommunications, transport logistics, and research infrastructure; overcome the technological gap of technology and innovation laboratories and industrial ecosystems. In the area of infrastructure, the actions underway are: (a) establishment of Innovation Institutes, Technology Institutes and the Open Labs network of SENAI; (b) creation of EMBRAPII units and EMBRAPII-IF centers; (c) development of the Advanced Manufacturing Plan (Federal Government, FAPESP, BNDES) and of BNDES' IoT study (basis for the National Plan of the Internet of Things, which is expected to be created by Presidential Decree).

(vii) ***Regional development***: Need to promote the inclusion and development of localities and regions that are relatively more backward in socioeconomic terms, by building on (discovery and/or creation) local "vocations". In this regard, the following main initiatives are underway: (a) *National Policy for Regional Development* (PNDR); (b) regional innovation support instruments (FAP, Banco do Nordeste - BNB, Fund for Scientific and Technological Development - FUNDECI); (c) Regional Development Centers of MEC, focusing on scientific and technological education based on regional specificities; (d) regional FIOCRUZ and EMBRAPA laboratories; (e) INCT network.

(viii) ***Regulation and reforms***: Need to timely regulate issues related to ethical, technical, economic and socio-environmental constraints arising from new disruptive technologies; urgency in updating outdated legal frameworks (e.g. legal Communications framework) or creating new legal frameworks (e.g. for IoT and IA). These issues are addressed through (a) the regulatory communications framework; (b) the civil framework for the Internet; and (c) various bills on digital transformation, biotechnology and nanotechnology.

10.3 The biggest challenge: policies to move faster than technological changes underway

This chapter has sought to evaluate the recent Brazilian experience with active industrial and innovation policies by identifying its legacies and challenges, especially those related to the development and implementation of a national strategy in the face of potentially disruptive technologies. On the one hand, the legacy of the pre-crisis strategic planning trajectory left institutional structures useful in several areas, which could be mobilized. On the other hand, the interruption of that trajectory meant the persistence of relevant challenges for which there are still no consensual proposals capable of mobilizing the main public, private and academic entities.

Some meritorious but disconnected actions underway partially address some of these challenges in the areas of governance, financing, support for SMEs, human resources training, infrastructure, regional development, and regulation. In the face of disruptive innovations, both the positive legacy and these initiatives can and should be exploited, expanded and improved by a comprehensive Brazilian strategy.

Considering the speed of recent technological changes, countries like Brazil will need to make firm and significant advances in basic research, laboratory and scientific infrastructures, and R&D and business innovation. It is therefore essential to boost Brazilian productive and innovative ecosystems and train our workers to cope with changes in work processes and in the job skills profile. This requires setting up a competitive economic base supported by endogenous and dynamic innovation processes.

The challenge is enormous: it is necessary to move faster than the technological frontier; otherwise we will experience, at best, a relative stagnation. Only a real historical leap forward in the innovative effort will enable a trajectory of sustainable development.

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11

ASSUMPTIONS, DIRECTIONS, AND STRATEGIES TO BUILD THE FUTURE OF BRAZILIAN INDUSTRY

Building the future of Brazilian industry is imperative. Combined and synergistic technologies offer windows of opportunity for building a competitive and sustainable future for Brazilian industry. The Industry 2027 project provided evidence on the stage of development of companies and ecosystems and characterized contemporary national innovation strategies. These strategies have many themes and priorities in common; however, there are major specificities related to each country. These directions will be described in this Chapter 11. In the first section, strategies will be presented by groups of companies and their production/innovative systems, followed by the trajectories of systemic policies.

11.1 Strategies differentiated by groups of companies and respective productiion/innovation ecosystems

The field survey carried out by the I2027 project clearly revealed three types of strategy in the Brazilian industrial sector in the face of disruptive innovations.

First, a still small group of companies with structured R&D activities and related to innovation ecosystems close to the technological frontier was identified. In view of these companies, 4G - the fourth and most advanced generation of management and manufacturing digitization comprising the entire value chain - will already be dominant in 2027. Therefore, these companies are eager to move quickly towards the new digital paradigm and to advance in cutting-edge innovation.

Second, there is a group of productively efficient companies that are generally exporters and, according to the econometric tests carried out, tend to be large. These companies understand the challenges posed by innovations with disruptive potential and are aware of the need to develop plans to pursue 3G and 4G digitization standards. Some already have permanent R&D and embryonic ecosystems activities in place, in collaboration with research centers. They need, however, incentives to accelerate their innovation strategies.

Third, a significant fraction of companies is not yet fully aware of the urgency of adopting manufacturing and management digitization strategies and, as a result, run the risk of losing viability in the face of a change scenario. In these companies, process and product engineering activities are scarce, and regular R&D practice is even scarcer.

Based on this differentiation criterion, which considers innovative training and productivity stages, respectively, in relation to the innovation and production frontiers, recommendations have been organized for private strategies. These recommendations are based on: (i) characteristics of demand; (ii) classification of companies by stage of capabilities in productive/innovative ecosystems; and (iii) nature and degree of difficulty of the challenges to be met. Based on these analyzes, different strategies have been proposed for the three groups of companies and their respective productive and innovative ecosystems, with specification of the relevant development, regulation and financing instruments to be mobilized.

11.1.1 Groups of companies and ecosystems that can evolve along with the technological frontier

Markets, production systems, and challenges

Customers of companies competing for the international frontier are informed and demand reliability, safety and a cost/performance ratio above existing goods and services. They are demanding users that take part in developments. Therefore, interaction between producers and users in the context of frontier innovation ecosystems is essential.

These companies are located in the following production systems and respective sectors: Aerospace & Defense - medium-sized and air transport aircraft, vertical takeoff and landing vehicles; Capital Goods - equipment, components (including electric motorization), and services for agribusiness, commercial transport, ultradeep water oil exploitation; Pharmaceuticals - biopharmaceuticals; Chemicals - bioeconomics companies; and ICT - management software, design services and engineering of solutions for IoT and advanced manufacturing, knowledge-intensive services (agtechs, for example).

In specific market segments, Brazilian industry is at the technological frontier. It is a legacy to be valued and expanded. These companies need to value themselves by offering goods and services in any geographic space, holding information and skills close to the best international practices. This requires companies to be able to incorporate new knowledge that is essential for technological convergence. Therefore, they need to co-lead multi-partner, interdisciplinary and internationalized ecosystems. As these firms compete for new markets through innovation, the number and profile of competitors can change, such as, for example, in bioeconomics. If there are barriers to entry, these can be overcome by success in innovation.

Strategy: innovate at the frontier

Innovation at the frontier organizes and guides corporate strategy to compete for innovation, differentiation, anticipation, and market creation. Competing for innovation also includes consolidation movements, joint ventures, asset acquisition/sale. These movements can enable shortcuts and competency and capability gains.

Competencies: Advanced R&D and co-leadership of productive and innovative ecosystems

The generation, use and dissemination of innovations that combine, in a synergistic way, different technical bases and interdisciplinary scientific knowledge require large investments in R&D and leadership in networks of productive and innovative ecosystems, involving permanent interaction with customers and partners. Companies need to be integrated and connected not only internally, but also with their suppliers of goods and services and their customers, to provide them solutions that generate value. They also need to be integrated and connected with ST&I institutes for the development of technologies. These challenges need to be addressed daily at top management level.

Ecosystems organized into interdisciplinary networks

Productive and innovative ecosystems must be strong, scientifically interdisciplinary, composed of integrated networks (including internationally) comprising universities, research centers, and component, equipment and service suppliers and customers. The speed to identify technological challenges and propose solutions is decisive.

Brazilian ecosystems, with proven performance and capabilities, must evolve along with the international frontier. On rare occasions in its history, and in a context of intense technological change, Brazil had today's stock of entrepreneurs and research infrastructure capable of meeting existing technological challenges.

However, this scientific, technological and entrepreneurial legacy needs to be retrieved and strengthened. Infrastructural and budgetary resources and incentives to the profitability of innovations need to be in place. The teaching of science, technology, engineering, and mathematics must be renewed towards interdisciplinarity, including in the fields of management and applied social sciences; networking should be increasingly interactive between institutes and corresponding laboratories; the environment should favor the emergence of knowledge-intensive startups and small technology-based companies in a long-term perspective.

Public-private concertation in programs and plans to compete in technological races

International experience and some recent Brazilian initiatives (EMBRAPII, *Inova Empresa*) show how essential it is to harmonize the development tools used with the needs of companies, based on consensual views on the technological challenges to be met. The dialogue between the public sector and representatives of supply and demand for technological solutions contributes to the understanding of market potentials, the definition of priorities, the alignment in the mobilization of instruments, and the engagement of companies and ecosystems.

The success factors for innovation ecosystems at the frontier are: (i) start from realistic assessments of existing capabilities, technology prospects and shared visions, including potential markets; (ii) coordinate public and private interests in specifying the critical challenges to be met; (iii) organize and implement actions through programs with explicit foci, targets, deadlines, and specified leadership; (iv) anchor programs in the coordinated and joint operation of public agencies, mobilizing the competence instruments of each one, in order to optimize the allocation of public resources; and (iv) monitor and evaluate results to ensure program implementation efficiency.

The public sector and the private sector are essential to finance the technological race

Enterprise and ecosystem financing must use all instruments available in Brazil - subsidies, credit and venture capital to support the entire innovation cycle - and be organized into innovative programs and projects that use the most effective instruments for each goal. Given the uncertainty of projects, the public sector and the private sector need to jointly participate in investments and share risks in successive stages.

Pursuing the frontier requires uncertain investments in relation to results. However, investments of this type often come true in projects with unprecedented ingredients and new technological concepts that require testing and validation. At this stage, research activities are generally carried out in the laboratories of universities and scientific research centers that rely primarily on public resources, including subsidies, and are relatively more important than private contributions.

Public support for research institutes in frontier projects should aim to find solutions to relevant societal challenges that can be met by technical progress and legitimized before society. The financing of programs or projects emanating from these objectives can be complemented with private contributions, at some level, because the success of the technological venture is also in the economic interest of companies. Technological development programs and projects of this nature must have a multiyear continuity assured, with attention to results (hits and misses are natural at this stage), in order to enhance the chances of success.

At the stage of prototype testing and construction of pilot plants for scaling-up and manufacturability purposes, the risks are lower; however, costs may be high, which requires continued public participation in partnership with private investment. The latter should benefit from financing with credit conditions (rate, guarantees, timeframes) appropriate to the technological risk. In turn, in the qualification and commercial operationalization stage, private investment should take the lead and may be supported by public or market financing.

At stages of uncertainty or greater risk, collateralized credit instruments (including in Brazilian R$) may not be adequate. Based on the assumption that potential returns stimulate risk-taking, the option falls on capital contributions, through reinvestment of retained profits or third-party investments in the companies or in projects of the innovative company or still through capitalization funds aimed at different segments (private equity, venture capital and seed capital). The risk-sharing model of projects is complex: on the one hand, a partnership is established around discrete and concrete undertakings, which enables isolating risks; on the other hand, the forms of intellectual/industrial property sharing as a reward for the taking the risks of the innovation are not trivial.

Public investment in technology-based companies through variable income funds is a usual and increasingly relevant practice in all countries, including the United States (using funds associated with the defense, energy, and health departments) and in Brazil, mainly through BNDES and FINEP. Initiatives of this type should be strengthened and expanded, primarily because they are implemented in partnership with private financial investors.

At the same time, strengthening entrepreneurial capacity to compete for productive and technological frontiers requires strengthening and expanding private funds capable of making capital contribution and providing technical and management support to companies with consequent business plans (investment thesis). Corporate venturing should also be incentivized, in its most varied forms. Tax regulations associated with financial investments in technology-based companies should recognize the extent of innovation within its definition of “risk”: hits and misses are inherent in the uncertain nature of technical progress.

Financing the diffusion of technological solutions is essential for industrial progress in that it creates and expands supply capacities and externalities. The diffusion of applied technological solutions (products, components, software, services) is indispensable for the construction of a competitive and sustainable industry. Financing the diffusion of these solutions will directly benefit user companies and, indirectly, provider companies. Brazil has long and vast experience in public financing for the acquisition of capital goods through the BNDES Finame program. The rules for access to this financing, previously based on nationalization indexes measured in terms of weight and/or value, have been replaced by the Computerized Manufacturing Accreditation (CFI) system. The new methodology, effective as of December 2018, values investment in innovation, qualification of the company’s’ workforce and use of components of high technological level and added value. This is an important step forward and must continue. However, the emergence of new technologies requires support with more favorable credit terms for mechanical or electrical equipment incorporating advanced digital technologies, equipment, software and services, including services required for M2M integration and the establishment of advanced manufacturing platforms and advanced ERP modules.

With regard to import tariffs, the decision on current and future tariff levels should not be based solely on the juxtaposition of local production prices versus imports at specific points in time and should not set high or low rates, whether homogeneous or not. In times of rapid technological changes, it is necessary to encourage the acceleration of processes for the diffusion of new technologies and use the same windows to open up spaces for competitive Brazilian entrepreneurship. It is important that the guidelines of the tariff policy organize and direct the potential for use, diffusion and generation of innovations in goods and services and not their tradeoffs.

Regulations and purchasing power to induce frontier innovations

The spectrum of regulations that affect the generation, use and diffusion of digital technologies analyzed here is broad: intellectual property, basic industrial technology, health, food security, environment, infrastructure, defense of competition, carbon pricing, and preference margins in public procurement, among others. Thus, making an effective contribution requires overcoming institutional challenges:

- Responsible public agencies or actions should converge and standardize concepts to be used in their rules and regulations (there are already concepts consolidated in international (including Brazilian) statistical innovation and research and development systems, for example).
- Regulatory frameworks need to be continually updated to incorporate technological solutions that can be commercially envisioned within five to ten years.
- It is necessary to give predictability to the availability of resources directed to funds, as well as their destinations, and the construction of technological scenarios can help build consensuses around the allocation of resources.
- It is essential to have partnerships between regulatory agencies and funding agencies around challenge-driven and program-organized initiatives for the promotion of technological development.
- Public agencies should invest in people and digital modernization to improve process efficiency, service quality and response speed, including accountability.
- Public procurement should be guided by missions to leverage priority programs associated with new technologies, under conditions of legal and regulatory security. The legal framework for public procurement must be improved accordingly.

11.1.2 Business groups and ecosystems that can keep up with the production frontier

Markets, production systems, and challenges

Generally, the demand trajectory is of increasing pressure for precision in compliance with specifications, up to the limit of customization of goods and services, and for the adoption of the "circular economy", in which waste and emissions can be used by the industry itself or recycled by other economic activities. Customers of intermediate goods, equipment or durable goods know what they want and their markets are transparent and well monitored. On the other hand, buyers of capital goods demand technical specifications, because their processes depend on the efficiency of the equipment and, for end consumers, the attraction is in price/performance aspects and the environmental sustainability of goods and services. In addition to specific technical innovations of various industrial activities, combined digital and synergistic digital technologies provide solutions towards precision and compliance with specifications.

The typical company in this group has well-developed competencies in terms of technical and business scale. These are efficient companies from the productive point of view, and they are found in the following production systems and their respective sectoral foci: Agroindustries - agricultural commodities, processed food products (larger companies); Capital Goods – power generation, transmission and distribution equipment, advanced machine tools, and industrial electrical equipment; Consumer Goods - large textile companies, home appliances; Automotive Complex - light vehicles, first-tier suppliers (auto parts); Pharmaceuticals – producers of generic or brand medicines; Basic Inputs - intermediate goods, including steel, pulp and paper, cement; Chemicals - large companies in intermediate products and specialties; and ICT - telecommunications network equipment, information access and capture devices.

Brazilian companies in these sectors/chains have technical and business scale and know how to be efficient. However, new references emerge: have precision in efficiency, be able to personalize customer service and combine scale with differentiation. On the one hand, it is necessary to combine scale with product differentiation or customization; on the other, it is necessary to increase efforts in engineering and regular R&D practice. The business itself is not at stake, as market participants are relatively established; it is the business models that are changing, driven by advanced digital technologies. If they do not adapt, companies can lose the competitive advantages already achieved. The sooner the majority of Brazilian companies move forward, the greater the likelihood of sustaining Brazil's competitive position.

Strategy: stay at the efficiency frontier, seize technological frontier opportunities

For these frontier companies, the main strategy in the face of disruptive innovations includes actions for them to advance or stay close to the production and technological frontier. In this group, those who do not move quickly and continuously will be left behind. The strategy to remain competitive must seek changes towards integrated, connected, and smart business models.

Competencies: integrated, connected, and smart companies

Implementing such a strategy requires building core competencies of integrated, connected, and smart companies. The company that succeeds in implementing a business model of this nature is different from the company that could already be considered to be integrated and connected. The "smart" component means that the company delegates to digital equipment with cognitive ability (embedded artificial intelligence) decisions regarding reactions to certain events. As much as solutions come from "outside", for companies to learn how to use, to modernize themselves and to navigate across unfamiliar areas while being safe, they must have the necessary and sufficient competencies to understand the "mechanics" of solutions, be able to identify their strengths and weaknesses and interact with suppliers to stay current. This requires expanding and strengthening permanent engineering and R&D activities and deepening the knowledge of markets to capture opportunities for product/service differentiation.

In this sense, it is also recommended to use (if possible, co-develop) and incorporate new materials into components and equipment and digital technologies to (i) interact in real time with suppliers and customers; (ii) develop products through product/process virtual modeling systems; (iii) manage production based on increasingly integrated M2M (machine-to-machine) communication solutions; and (iv) manage the business with artificial intelligence and big data support.

The direct involvement of top management is a necessary condition for the success of undertakings such as these. Only with the involvement of business leaders, companies will be able to keep pace with world technical progress, with the support of their productive and innovative ecosystems.

Ecosystems organized to interact

To keep up with the production and technological frontier, ecosystems associated with business strategies should support the use and development of products and processes that contribute for the establishment of integrated, connected and smart companies. To evolve at the frontier, the scope of the field of scientific and technological knowledge tends to be relatively narrower than cutting-edge research. However, in order to provide advanced solutions, these ecosystems must be able to integrate and connect, in a smart manner, their different participants: interdisciplinary providers of goods/services, human resources, specialized technical services, and technological research. Companies wishing to co-lead the frontier need to firmly engage in product and process development, and this must cover the entire production chain.

In summary, recommendations to the companies in this group include:

- Engaging in product and process development, covering the entire production chain.
- Prioritizing the regular practice of engineering and R&D activities.
- Evolving towards interdisciplinary networks (including international ones) with universities, research centers, suppliers, and customers.
- Favoring startups in hubs and incubators (technology-based startups require long-term support).
- Quickly identifying technological challenges and proposing solutions.

Sharing funding and risks

For companies that are investing in innovation in partnership with their ecosystems, the recommendations are the same as those for companies that want to evolve with the technological frontier. And it could not be otherwise: organization in programs and projects, co-financing with the significant presence of public assistance.

Private participation should be more expressive when company investments are geared towards introducing and/or advancing the use of new technologies. The rationale in the use of own resources lies in the (usual) low relation between investment in new technologies and total investment, as well in the attractiveness of the expected rates of return. Companies must also be attentive to corporate venturing in technology-based companies (whether emerging or not), precisely to have among their assets competencies to "understand" the use and undertake new businesses with flexibility. Public funding, in these cases, should only complement the contribution of private resources in the acquisition of solutions that involve a greater risk.

Regulations to ensure precision, quality, safety (including of data) and environmental sustainability

Basic industrial technology, health, food security, environment, defense of competition, consumer protection, data security and privacy, carbon pricing: such is the range of relevant regulations. Responsible agencies are advised to ensure quality, safety, and environmental sustainability; and to promote market structures that are permeable to entries and flexible in the face different business formats.

11.1.3 Groups of companies and ecosystems that can shorten the distance to the production frontier

Markets, production systems, challenges

There is great heterogeneity in this group of companies. The markets of final goods or of equipment and components vary considerably, as do the companies' value chains, processes and products, and size. Markets can be segmented based on the demand and/or income level of users. However, a current trend for all income brackets is the increasing demand for price-weighted quality in all segments.

Market segmentation based on quality and price will always exist, but the latitude will be narrower, for three reasons: (i) slower expansion of the markets catering to more demanding middle classes, whose real incomes do not match their aspirations; (ii) successful entry of new competitors with significant shares in other markets; and

(iii) marketing pressure that disseminates voluminous, global information and fuels the expectations of consumers and producers of goods.

The typical company in this group has a low level of sophistication, lacks capabilities and has limited access to resources; however, because it has a family structure and a more horizontal management, it has greater decision-making flexibility. These companies are generally found in the following sectors: Aerospace & Defense; Agroindustries; Capital Goods; Consumer Goods; Automotive Complex; Chemical; and ICT.

Companies operating in less demanding markets are generally smaller and have limited competencies. The economic importance, especially for employment, of smaller companies is undisputable. In addition to success stories, which should be valued and used as reference, in all countries, especially those at an intermediate level of development like Brazil, the challenge for companies is to mitigate the limitation of these competencies and strengthen their potential advantages.

They occupy niches where entry barriers are not high and the volumes of capital required are low. The competition is fierce: companies compete for spaces against many others, which is only possible due to an equally varied demand in terms of price/performance of goods and services. On the other hand, these companies have business flexibility: the possibility of rapidly changing structures (and without high organizational complexity), management (including financial), acquisition of inputs, production batches, and product mix.

To a large extent, the design of these companies' products is simple and known, and they are users of process innovations developed by suppliers of equipment, inputs and services. In some cases, these are specialized suppliers; in others, they are equipment manufacturers, digital solution providers (management software), providers of specialized technical or innovation service. Whether specialized or not, these suppliers disseminate innovation to smaller companies.

Strengthening the companies in this group requires implementing digital solutions to fight competitors who can offer better products at competitive prices. However, due to the diversity between these companies, not always the most advanced digital generation is - and should be - the preferred solution to strengthen competitive capacity. And even if investment in new technologies accounts for a significant proportion of the total investment, localized solutions are available that result in interesting rates of return. The introduction of new technologies, at any level of intensity and sophistication, implies significant organizational changes.

Strategy: shorten distances to the production frontier to anticipate competition

For these companies, the key strategy in the face of disruptive innovations should be to invest in the knowledge and implementation of digital solutions to strengthen business management and the capacity to deliver quality and competitive pricing.

Competencies: know how to choose and implement appropriate technological solutions

The essential competency is the capacity to manage the business, especially production, but also learning to know and be able to specify and implement the most appropriate technological solutions.

Unlike in capital-intensive industries, investment in new technologies represents almost the totality of investments in new facilities. The diffusion of new technologies should be uneven and occur initially in manufacturers targeting high-income consumers and specialized market niches. In mass consumer markets and for smaller producers, the diffusion process may be slower and implemented in stages or by modules. The coexistence of production lines, products and business models of different generations is likely to occur.

New technologies have the potential to positively change competitiveness conditions in Brazilian production in two directions. First, because innovations can be introduced by modules or segments, productivity can be gradually increased. Second, this is because digital-based automation confers greater flexibility to processes, enabling product customization and increasing response speed in the face of market changes. Digitization technologies have already reached a mature enough stage for the pace of change to depend mainly on the companies' decisions to modernize their business models and know how to specify the provision of the best technical solutions.

Ecosystems organized to provide support services

For companies with limited competencies, the difficulties of adopting new technologies may be associated with the lack of knowledge of entrepreneurs and to the companies' limited resources. Productive and innovative ecosystems must provide adequate solutions at compatible costs. Suppliers of components, goods and services, including specialized technical services in basic industrial technology and management support, are the relevant actors to induce the strengthening of companies. The three main components of business support ecosystems are detailed below.

The first component consists of suppliers of equipment, machines, software and, increasingly, of suppliers of digital integration services. These suppliers must be nearby and provide goods and technical assistance services before, during and after a sale. It is necessary to understand how it works and act in an environment of high demand diversity. This is only possible through digital connection with customers and the provision of service platforms, from which suppliers can track and meet their customers' needs.

The second component is formed by specialized technical service providers (basic industrial technology). The Brazilian network of both public and private service providers, such as SENAI's technological institutes, is extensive, but scattered from the geographic, thematic and sectoral point of view. The technical references are organized by the ABNT-INMETROsystem. It is an asset to be valued and expanded, which must have its contents updated by the adoption of digital technologies, with the double objective of establishing close relationship with the companies and offering services compatible with new digitization standards.

The third component includes providers of business assistance to companies, mainly in the area of management, such as small software service companies and the SEBRAE system. These networks of consultants and specialized providers should expand their sectoral and locational coverage and be accessible at a low cost. They are essential to promote the wide diffusion of new digital management practices through the incorporation of ERP adapted to SMEs and also through the incorporation of digital systems for connected production, with environmental sustainability and energy efficiency.

Unlike the two groups previously addressed (companies focused on frontier innovations or companies capable of keeping up with the best digital practices), the group of companies that should shorten distances to the viability frontier are the providers of solutions – of different types – that should lead the organization and the activation of innovation support ecosystems. Overcoming constraints related to information and business capabilities to advance the productivity and competitiveness of companies requires leadership and proactivity of the three aforementioned support ecosystems.

Given the breadth and variety of institutions capable of delivering services of this nature, organizational initiatives in demand-driven service provider networks should be valued. Worth mentioning are initiatives organized to meet **actual demands**, which can be better coordinated by sectoral business associations or groups of companies of Local Productive Clusters. The local and territorial components are highly relevant for this Group of Companies and Ecosystems.

In summary, for the ecosystems in which the companies furthest away from the technological frontier are included, the following recommendations are in order:

- Public and private technological support institutions and SENAI Institutes should seek to lead ecosystems that aim to support and mobilize companies.
- Technical service centers should offer digital solutions to promote basic industrial technology.
- Institutions supporting business management, such as SEBRAE, should promote the massive diffusion of new practices associated with digital technologies.
- Participants in production chains (especially upstream or downstream large companies) should participate in ecosystems to qualify their suppliers or customers.
- It is useful to promote experiments demonstrating digital solutions such as production lines and testbeds.

- The articulation of demand for these support services should prioritize local productive clusters and local business associations, especially in less developed regions, and networks of service providers should be prepared to serve them with priority.

Financing and incentive to the diffusion of new technologies

The diffusion of technological solutions among smaller companies must be far-reaching and rapid. Efforts in two directions should be undertaken: on the demand side, by disseminating knowledge and promoting the use of these solutions; and on the supply side, by strengthening the capacity to provide adapted and efficient solutions.

Support under conditions favorable to smaller companies is a relatively high consensus among scholars and policy makers, including in Brazil. In this regard, the two challenges to supporting the diffusion of technical modernization solutions re: increase the internal motivation of companies and prepare them technically, on the one hand, and induce external pressure (from consumers and suppliers themselves) for modernization on the other. Since the support for companies implies favorable financial conditions, it is necessary to specify counterpart targets associated with the diffusion of new practices. Action indicators in this direction should be constructed from a time base of reference and associated growth rates.

There are successful experiences of incentive to the modernization of companies, both international and in Brazil. Volume and source of resources are policy decisions, which will, however, be defined by the priorities set by the country's executive administration. Brazil does not lack sources, and volumes vary with each administration period. Regardless of the volume and source of resources, successful experiences reveal two necessary but essential requirements: the availability and predictability of resources. In turn, the results and financial accounts are rendered in a systematic, recurring and transparent manner, including with third-party evaluators.

Financing the diffusion of technological solutions is essential for industrial progress in that it creates and expands supply capacities with increased productivity. The diffusion of technological platforms or applied solutions (products, components, software, integration services) is imperative for building of a competitive and sustainable industry. Financing the diffusion of these solutions will directly benefit user companies and, indirectly, provider companies. Brazil has long and vast experience in public financing for the acquisition of capital goods through the BNDES' FINAME program.

The rules for access to this financing, which were previously based on nationalization indices measured in terms of weight and/or value, have been replaced by the CFI system. The new methodology, which enters into force in December 2018, values investment in innovation, qualification of the company's workforce and use of components with a high technological grade and added value. This is an important step forward and must continue. The emergence of new technologies requires support with more favorable credit terms for mechanical or electrical equipment incorporating advanced digital technologies, equipment, software and digital sensing services as well as connected manufacturing and management integration. The financing of complete packages for the establishment of platforms or modular solutions should be reviewed with priority.

For these companies, two types of non-financial incentives can be distinguished and should be promoted by the government.

The first is incentive *through programs of specialized technical services*. As in the case of recommendations to evolve or keep up with the frontier, in public actions incentives should favor ecosystem programs targeted at specific challenges in providing specialized services, organized into regionalized networks of service providers, with targets for expanding service provision, under the leadership of the institution with the best proven capacity to manage complex projects. Public funding should encourage support programs as well as the adjustment of institutions to new digital technologies. Despite the limited availability of resources on the business side, their financial participation should be mandatory, even if initially just symbolic to then grow proportionally to their business success rate.

The second is *incentive through business assistance programs*. This type of incentive includes the diffusion of new management practices and digital technologies through business assistance programs, in which specialized and qualified technical consultants provide assistance directly to companies. The induction of learning by users can be enhanced by collective learning. Programs of this nature should be organized for groups of companies that share lessons learned (as long as this does not affect the business strategy) to reinforce collective learning, including by service providers and financing institutions. The organization of the institutions involved in this type of incentive can vary in terms of the amount of resources and focus - spatial, sectoral or thematic: the Brazilian model, for example (More Productive Brazil program), is different from the Chilean, Singaporean or German models. Regardless of the organizational model, what matters is the capacity of networks to meet local demands.

Recommendations on financing and incentives can be summarized as follows:

- Programs for the provision of specialized technical services should be oriented to meeting specific challenges related to basic industrial technology, with expansion goals and organized into networks (e.g. SENAI networks).
- Programs in support of business management (such as the More Productive Brazil program) should be massively and significantly expanded with the aim of disseminating digital solutions appropriate to the profile of the companies with spatial, sectoral or thematic foci and duly established goals and counterparts.

- It is essential to finance the acquisition of equipment, software, sensing services and integration of connected manufacturing and management platforms and modules for SMEs, under favorable credit conditions.

Regulation: induction of externalities to the industry

Basic industrial technology, health, food security, environment, defense of competition, consumer protection, data security and privacy, carbon pricing: this is the range of relevant regulations. Responsible agencies are advised to ensure quality, safety, and environmental sustainability; and to promote market structures that are pervious to entries and flexible to different business formats.

11.2 Priorities, construction of externalities and capabilities, new themes

11.2.1 Assumptions and prioritization of policies

Building the future of industry starts from a set of assumptions. The first of these assumptions is to value legacies of entrepreneurial, technological, and scientific competencies, including recent policy and program experiments, so as to learn from mistakes, solidify successes and leverage strengths. The second is to unveil and explore opportunities based on the existing capabilities and the potential envisaged by the companies. The third assumption is the need to build consensus and public-private concertation around a common national vision to be shared with society. The fourth assumption is to recognize and address society's aspirations for quality of life and environmental sustainability and to discuss extensively new ethical and regulatory issues. The fifth and final assumption is the urgency of moving forward with ambition, realism, pragmatism, resilience, focus, and long-term vision.

Building the future of industry requires policy prioritization, that is, it requires not only the direct involvement of the highest level of government, of business leaders and of workers' and civil society organizations in the construction of this long-term vision, but also the investment of significant and predictable financial resources in ST&I over a long period of time.

Thus, **building the future of industry requires directions in order to** (i) build foundations and externalities for all, so as to train skilled human resources and capable SMEs; (ii) modernize and increase the response capacity of the State, updating and creating pro-innovation regulatory frameworks; (iii) coordinate and use instruments and programs based on cooperation especially among regulatory agencies and federal funding agencies; and (iv) ensure legal certainty to incentive processes and introduce new ethical and regulatory issues on the public agenda.

These directions will be described below. The following are macro-systemic, necessary and facilitating conditions: the sustained resumption of economic growth, the existence of competitive interest and exchange rates, the implementation of institutional reforms (tax, fiscal, financial), the ease of doing business, legal certainty, and the steady recovery of investment in infrastructure. Notwithstanding the relevance of these macroeconomic conditions, the implementation of a national innovation strategy requires persistence and long-term vision and should not be vulnerable to cyclical fluctuations in the economy.

11.2.2 Directions

Foundations: externalities for all

Regarding the qualification of human resources, public and private vocational training systems in Brazil, and especially in SENAI, play the role of strategic agents to promote the improvement of the qualification profile of our workers. Steps must be taken toward evolving from "training centers" to "learning centers"; expanding and diversifying vocational training programs to develop and renew skills throughout workers' lives; anticipating needs in terms of workers' skills, qualifications and talents, based on companies' needs.

It is also essential to take steps for introducing the teaching and use of digital technologies at all educational levels and to promote broadly studies and debates on the impacts of new digital technologies on employment, occupations, skills, work, incomes, and social benefits.

To improve the capabilities of SMEs it is necessary to massively expand programs on entrepreneurial training, technical assistance, and provision of technical/metrological services, such as the More Productive Brazil program. However, these programs should prioritize the need to disseminate management and manufacturing digitization. Therefore, they should promote rules and standards (ABNT and INMETRO) that facilitate the diffusion of new technologies, ensure interoperability and guide the operation of existing networks that provide assistance to SMEs; disseminate integrative digital solutions and software, modular experimental platforms, including for lean manufacturing and energy efficiency. This can be done through SENAI's network of Technology Institutes and Innovation Institutes, in partnership with SEBRAE.

The diffusion of new digital manufacturing and management platforms can be financed through public financial institutions and should be based on new digital systems and simplified automatic procedures. Other credit, subsidies and venture capital instruments can also be mobilized to structure permanent engineering and R&D activities in SMEs.

Finally, special mention should be made of the importance to strengthen incubator and accelerator networks and ensure favorable tax treatment to venture capital funds.

For an integrated, connected, smart, mission-oriented state

Just as companies must evolve towards integrated, connected and smart business models, the Brazilian State must also follow this path, seeking an integrated, transparent, connected and smart performance. Digitizing the State is a fundamental condition for achieving efficiency gains, reducing costs, increasing transparency, improving quality, and speeding up services (red tape reduction).

To advance in this direction, it is necessary to build capacity in public managers to prospect, plan, implement and evaluate programs for the generation, use and diffusion of new technologies. It is also necessary to coordinate agencies and institutions and to ensure consistency in the management of financial and non-financial instruments through integrated, smart and transparent management systems. Thus, policies will be implemented through programs and instruments that are coordinated with each other and in tune with the needs of companies and the monitoring of results will be ensured.

Contemporary and efficient regulations

Regulations should be efficient and innovation-driven. However, this requires updating existing legal frameworks and/or creating new frameworks and regulations involving telecommunications, ST&I, government procurement, biodiversity, network privacy and security, “Civil Framework for the Internet of Things”, research and applications derived from advanced genomics techniques. Advancing in this direction also requires speeding up the process of building capacity in and digitizing regulatory agencies/and public companies, particularly INPI, ANVISA, ANATEL, ANTT and IBAMA.

With regard to sectoral agencies, urgent steps must be taken to converge and standardize normative concepts related to innovation and R&D - including those adopted by the Brazilian Federal Internal Revenue Service, the Public Prosecutor’s Office and control agencies such as the Federal Court of Accounts, the Federal Comptroller’s Office and the State Courts of Accounts - with a view to increasing efficiency and legal certainty for the enjoyment of the incentives provided for by laws. In addition, sectoral funds managed by sectoral agencies should be made available on a predictable basis and partnerships should be forged with funding agencies around challenge-driven technology development initiatives organized by programs, in line with the successful experiences of the Brazilian Company for Industrial Research and Innovation (EMBRAPII) and of the *Inova Empresa* program.

Expanded incentive with legal certainty

Incentive instruments should be decompressed and expanded, with legal certainty, efficiency, targets, counterparts and result evaluations. Therefore, it is important first to decompress federal funds allocated to the ST&I system and increase the scale of support to innovation provided by federal financial institutions through more financing, including non-reimbursable financing, and more capitalization at appropriate costs and conditions (examples such as those of EMBRAPII should be strengthened and expanded). Projects and programs should be defined at the highest levels of government, with goals shared with the private sector. Moreover, additional funds should be allocated - on a predictable basis and without the possibility of the Federal Government using them to pay other bills or reduce spending - to building capacity in public and private science and technology institutions. Finally, it is crucial to secure resources for the different phases of priority projects, especially during the scaling up and manufacturing phases.

Improvement of the Law of Good and other regulations

The Law of Good needs to be improved by increasing its deductions, enabling accessibility by small businesses, allowing for external R&D to be partially hired, including incentives for investing in startups, seed capital, angel investors, venture capital and corporate venturing. But that is not all: it is also indispensable to ensure the convergence of infralegal concepts and rules. Uniform application criteria should ensure the legal certainty necessary for enjoying the incentives provided by law. These same recommendations should be applied to the Informatics Law and to PADIS.

Society should discuss new ethical and regulatory issues

Disruptive innovations raise new relevant ethical and regulatory issues that are being discussed in developed societies, with the active involvement of the scientific and technological community, opinion makers, and civil society entities. Brazilian society needs to and should discuss these new issues broadly.

It is recommended that industry contributes to and participates in a broad and representative discussion to identify proposals concerning, for example, the following ethical and regulatory issues: personal privacy; use and manipulation of human, animal and plant genomes; database ownership and personal property rights of citizens; properties and rights of protection of genomic data or biodata data of persons or living organisms; security of company data and information; interoperability of standards and communications protocols, IoT, advanced manufacturing; and recycling of inputs, parts and pieces and equipment related to bio- and nano-materials and digital technologies.

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FINAL MESSAGE

A Brazilian national strategy needs to be urgently developed, seeking to seize opportunities and mitigate the risks associated with disruptive innovations, so as to ensure a competitive and sustainable future for Brazilian industry. This is the task for now and for the next ten years.

Brazil can and must make progress with ambition, realism and pragmatic proposals that can be implemented in the short term, but also with resilience, focus and a long-term vision. This requires overcoming the dichotomy, sometimes deeply rooted in Brazilian society, which opposes the public sector on the one side and the private sector on the other - as if socioeconomic development were possible based *only* on the State or *only* on the market.

History shows that successful countries have established - and continue to create - institutional arrangements that promote synergy between State and market. In order to implement a national strategy in the face of disruptive innovation, a solid and synergistic partnership between the public sector and the private sector is crucial. It is also essential that both sectors work in a concerted manner to create consensus and legitimacy before society of ST&I and industrial promotion initiatives whose impacts are not always obvious and short term.

The direction of competitiveness is established; always respecting the specificities of competition in each market, the competitive company is integrated, connected and smart. And the future of industry can only be built through continued investment in capacity building, under long-term plans implemented day after day with tenacity.

New combined and synergistic technologies create opportunities and are instrumental for Brazilian industry to develop skills, capture spaces to compete, create jobs, produce new goods and services and contribute to raising the quality of life of our people.

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