Biotechnology as the basis for an endogenous core in Argentina

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Received: 04/12/2023
Accepted: 17/03/2025

Abstract

This article is based on the assertion that the existence of a dual techno-economic paradigm at the global level creates possibilities for the formation of a biotechnology-based endogenous core in Argentina. We argue, firstly, that key innovations are being defined in the field of biotechnology, in industries that are strategic owing to their significant impact on the health and food supply of the global population. Secondly, Argentina has considerable techno-productive capacities in these industries. Through a series of coordinated technological and industrial policy interventions, these activities could fulfil a pivotal role in sectoral specialization as part of a structural transformation programme.

Keywords

Biotechnology, information technology, communication technology, economic development, industrialization, industrial development, industrial organization, technological change, Argentina

JEL classification

F63, L16, O33, O25

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I. Introduction

Argentina, a semi-peripheral economy with a highly heterogeneous production structure specialized in exporting primary goods and other minimally processed products, faces serious limitations in strengthening its industrialization. Following various experiments with opening and liberalization, the Argentine economy has failed to develop increasingly sophisticated techno-productive capacities, and has maintained a socially regressive structure exacerbated by new external debt arrangements.

In the 1980s, Fernando Fajnzylber (1983), an economist with the Economic Commission for Latin America and the Caribbean (ECLAC), put forward the idea of formulating a development strategy that would move away from that regressive path, based on what he described as an endogenous core for a technological boost (p. 374), meaning the establishment of a national coalition of businesses and scientific and technological bodies that would encourage the absorption of foreign technology and, by building productive capacities in "pivot" sectors or activities, would support a change in the economic integration of the region's countries.

The persistent crisis in Argentina has been worsened by the regressive structural change in peripheral economies, which is related to contemporary changes in the globalization of capital and the institutional self-reinforcing mechanisms shaping current national trends. This situation leads us to revisit Fajnzylber's proposal and ask, in practical terms, what endogenous core could serve as a basis for structural change in Argentina.

The tradition of heterodox economic thought in Argentina has not provided a meaningful answer to that problem. There is, however, a prevailing consensus based on certain readings of the international literature, which has not always been properly understood. This answer could be phrased as follows: structural transformation should be based on the adoption of the means of production, production techniques, organizational principles and infrastructure of the new techno-economic paradigm, which in turn is shaped by the information and communications technologies (ICTs) known as Industry 4.0 (Basco et. al., 2018; Economic Commission for Latin America and the Caribbean [ECLAC], 2019).[1] The minimal formula may be expressed as follows: endogenous core = ICT, from its key factor, namely the microprocessor, through to Internet infrastructure and new information technologies focused on artificial intelligence.

Despite the obvious appeal of this approach for strategic discussion forums and large providers of Industry 4.0 technologies, it poses various problems. Firstly, once a distinction is made between leading industries (providers of the constitutive parts of the new paradigm) and adopting industries (which are rejuvenated as a result), it is clear that, given the existing technological and institutional barriers, countries such as Argentina do not have the necessary capacity to achieve dominance in the high-innovation segments of the leading industries under the new paradigm. The outcome may be less an endogenous core than a new form of peripheral integration into the global economy. This issue, which is a result of the size of the current gap between domestic techno-productive capacities and those of global industry leader countries, has been amply discussed in the domestic literature (Moncault et al., 2022; Motta et al., 2017).

The second problem depends on the characterization of international technological conditions, i.e. whether ICTs are successfully established as the fully dominant paradigm or, on the contrary, their cross-sectoral reach is more limited (Tylecote, 2019). This leads us to consider industries in which the key innovation that defines the technological trajectory rests on a knowledge base other than that of electronics and information technology.

The purpose of this article, which reflects a stage of initial exploration, is to reinterpret the current productive transformations of the global economy and examine opportunities for creating a new biotechnology-based endogenous core in Argentina. We argue, firstly, that key innovations are being defined in the field of biotechnology, in industries that are strategic owing to their significant impact on

[1] For a discussion of the limits of the concept of Industry 4.0 see Brixner et al. (2020).

the health and food supply of the global population, and secondly, that Argentina has considerable techno-productive capacities in these industries. Starting with a series of coordinated technological and industrial policy interventions, these activities could fulfil a pivotal role in sectoral specialization as part of a structural transformation programme.

In order to develop this argument, we begin with the assertion that the techno-economic paradigm in this historical period includes at least two coexisting technology constellations, whereas the prevailing view is that biotechnology is a form of information technology. The role of ICTs is dominant but by no means absolute. Biotechnology is a relatively autonomous field of inquiry, enabling the dissemination of key innovations across a range of highly technologically dynamic industries, and paving the way to explore new, non-subordinate modes of integration into the global economy.

The article is structured as follows: the concept of endogenous core put forward by Fajnzylber in the 1980s is set out in part II, then the dual techno-economic paradigm is fleshed out, and the idea of a "key factor" is reformulated on the basis of the relationship between recombination technology and support material. Part IV includes an account of the mesoeconomic specificities of the industries whose key innovation is biotechnology. In the following section, a comparative analysis is provided of the existing productive capacities in Argentina in the industries whose key innovation is ICT or biotechnology. Lastly, we conclude with a discussion of the limits and opportunities for the development of a biotechnology-based endogenous core in Argentina.

II. The endogenous core for a technological boost

One of the greatest theoretical and methodological challenges in the social sciences when considering economic development is identifying the technological and institutional conditions necessary for transforming national production, taking into account the techno-economic shifts under way in the global economy (Gershenkron, 1968).

Drawing on the tradition of heterodox Latin American thought, Fernando Fajnzylber (1983) suggested rethinking the relationship between the internal and external conditions of economic development.[2] This task involves, on the one hand, reassessing the nature and characteristics of innovations that shape the technological trends in the global economic system and, on the other hand, analysing what the author calls the "self-determination reserves" (Fajnzylber, 1971) available to Latin American countries in order to define their path to specialization amid a shift in the historical conditions of production. These self-determination reserves are expressed in the concept of an "endogenous core".[3]

Fajnzylber called for the creation or substantial strengthening of an endogenous core consisting of domestic public and private actors and businesses focused on production, engineering, research and development, and centred on certain sectoral specialization "pivots" that could combine the most dynamic international industry perspectives with existing domestic potential. Already in the 1980s, he pointed to (micro-) electronics and genetic engineering as the technologies that could underpin the sectoral specialization pivots that would enable Latin American countries to overcome the restrictions and accumulated delays affecting their production structures.

The endogenous core is what makes it possible to link international technological opportunities and the existing sectoral trajectories in the different countries.[4] Using that core, it is possible to advance

[2] For an assessment of Fajnzylber's contribution to Latin American thinking on economic development see Torres (2006).

[3] Fajnzylber (1983) maintained that the endogenous core included the formation of a given alliance of social forces with a historical memory, a vision for transforming the economy and society, the will for national self-assertion and the capacity to sustain effective leadership over the majority segments of society.

[4] The productive branches of these new technologies account for most of the investment in research and development at the global level. They determine the degree of linkage in the industrial matrix and momentum in productivity (Fajnzylber, 1983).

from the mere adoption of imported technology to "creative learning", in which technologies are adapted to national specificities, in a process of adopting and absorbing foreign technology. The absence of an "endogenous core" leads to the "grotesque imitation" of imported technologies, which countries in the periphery adopt as mere users, thereby confining themselves to the least complex segments of production, resulting in persistent foreign currency deficits.

According to Fajnzylber, these are the strategic considerations that matter when designing an industrial policy. Various public interventions in the productive sector, starting in the post-war period, led to implementation of large-scale strategic programmes and projects aimed at the adoption of new technologies. These have now been revisited, in the form of what are known as mission-oriented policies (Ergas, 1987; Mazzucato, 2018). These policies have in turn been combined with actions that extend targeted support to the pivot branches, so that local companies can fast-track the adoption of creative learning by various means, including trade measures and strategic campaigns related to intellectual property and public procurement. In that vein, Fajnzylber was inspired by the post-war experience of the Republic of Korea, which implemented a strategy based on creative learning by adopting imported technology through a deliberate and targeted approach focused on a well-defined (if shifting) set of pivot branches ranging from chemistry and metallurgy to electronics and other consumer durables (Amsden, 1989; Chang, 1993).

It is crucial to consider what form the endogenous core currently takes in the United States and China as they vie for leadership of the global economy. Although the United States has an innovation system in which the financial market plays a leading role in the development of risk capital, and an intellectual property regime that encourages start-ups, the State does have a hidden role, particularly when its technological superiority in relation to military applications is under threat (Coriat, 2002; Wade, 2017). The purchasing and contracting of technology by certain government agencies involved in defence and energy, and the development of strategic public-private initiatives in advanced manufacturing,[5] play a central role in building the endogenous core. The Department of Defense became one of the main creators of the endogenous core by financing the establishment of large research and development laboratories in universities and boosting big domestic companies such as IBM, Westinghouse, Philco-Ford and, more recently, Intel, Apple, Microsoft and Amazon (Wade, 2014).

Meanwhile, China has in recent years been implementing its Made in China 2025 and Internet Plus strategies. Made in China 2025 is a strategic plan geared towards technological progress in global value chains and developing advanced manufacturing capacities in areas such as digital platforms and electronics. In the second phase (2026–2035), the plan is to continue promoting such progress in basic electronic and IT devices in order to become a leader in new product design in the period 2036–2049, and hence to control every stage in the value chain (Li, 2018). With a global expansion leveraged on its large domestic market, the Internet Plus strategy is aimed at developing the country's own 5G mobile phone network and boosting telecommunications infrastructure, which is at the heart of the country's rivalry with the United States.

III. The dual techno-economic paradigm and the key factor

In order to make progress in defining an endogenous core, the first element to consider is how to characterize the innovations that determine the technological trends in the global economic system. That dimension of analysis has been addressed in the literature on the basis of the techno-economic paradigm, which is structured around the existence of a plentiful and cheap input or material (such as coal, steel or oil) and a new processing technology (such as the steam engine, the Bessemer process

[5] A good example of that type of initiative is the formation of the public-private consortium SEMATECH to develop and sustain the global technological leadership of the United States in the semiconductor industry (Wade, 2014).

or the combustion engine) which, when combined, enable "quantum" leaps in productivity as compared with the previous paradigm (Freeman and Pérez, 1988; Pérez, 2010). Those elements shape the motive branches (which produce the key input and develop the processing technology) and the vector branches (which make intensive use of those elements to develop new products) of the new techno-economic paradigm. These are associated with new patterns in the organization of production. In order to be viable, they need infrastructure and a socioinstitutional context. As a result, there is a possibility that the paradigm itself could enter into crisis (Tylecote, 1992).

The technological revolution in ICT from the 1970s onward was not, however, associated with a new wave of accumulation and employment expansion (Archibugi, 2017; Gordon, 2000). Two factors could account for that "explanatory gap" in the theory of techno-economic paradigms. Firstly, "neoliberal" institutional arrangements could be ill-suited to the establishment of ICT as a new techno-economic paradigm (Tylecote, 1992; Rivera Ríos et al., 2019). Secondly, the shift in the technological foundations of contemporary capitalism tends to destabilize some of the common components of the previous techno-productive revolutions, on which the very category of techno-economic paradigm was based. The explanation for the transition to the new economic paradigm thus includes an element that does not fit easily into the aforementioned model, i.e. the idea of technologies that now process information, instead of a natural resource.

One question that may arise in this context relates to the level of generality of the new techno-economic paradigm based on ICTs and its relationship with biotechnology. A first explanation, which we could call the "convergence thesis", would imply seeing biotechnology as one more variant of information technology. Biotechnology would thus increase the level of generality of the ICT-based techno-economic paradigm. If DNA is information, biotechnologies would be included in the ICT-based techno-economic paradigm through the convergence of knowledge bases and technologies. According to that line of reasoning, information technology —and biotechnologies, which would be subsumed into that category— form part of a paradigm that differs from earlier ones in that the crux of the innovation process would not be the transformation of an energy input or a new material, but rather the recombination of information. Such would be the nature of the paradigm shift.

A second possibility, which is raised in this paper, involves considering a deeper process of differentiation, which could be termed a "coexistence thesis" implying that biotechnology is to some extent not reducible to ICTs. This perspective is based on the idea that innovation processes in the two areas do not arise solely from progress in technologies for recombining information, but that the support material on which the technologies act is also key.[6] In the case of ICTs, the key innovation is a process technology (i.e. information technology) that conducts productive processes through an inanimate support material (micro- and nano-electronic devices). It consists of "smart" machines with sensors and stable electronic interfaces that work by using telecommunications infrastructure. Since the development of DNA recombination technologies (from cloning and transgenic vegetables to the most up-to-date gene editing technologies), biotechnology has acted on live matter (such as cells and seeds) and affected biological processes. In other words, it consists of innovations whose material supports are, intrinsically, biological systems in which the interface between components is highly unstable (Pisano, 2006; Pisano and Shih, 2012).[7]

On the basis of these considerations, the categories associated with the concept of the techno-economic paradigm can be reformulated to take a different approach from that of the neo-Schumpeterians to the role of key innovations in the leading industries of contemporary capitalism. The proposed conceptualization is outlined in table 1. The starting point is a dual paradigm that includes ICTs as a cornerstone but also addresses biotechnology —in a role that is more limited, but still significant for the present and with high potential for the future. In contrast with the neo-Schumpeterian account, the paradigm shift is less about combining a key input and a processing technology, than

[6] For an analysis of the relationship between technology and support material see Zukerfield (2018).

[7] Biotechnology acts on microorganisms and parts thereof which, in turn, act on a complex system that cannot be fully disaggregated and is highly unstable in its interfaces. The latter, unlike algorithmic, metallurgic or electronic developments, cannot be easily modularized.

about recombining information that acts on a specific support material. In the case of ICTs, it consists of the relationship between information and electronics; in biotechnology, of the relationship between biotechnology, i.e. genetic engineering, and living matter. We are thus looking at the coexistence of two key innovations that will, as Dosi (1982) points out, be associated with two technological trajectories with different heuristics and different degrees of cross-sectoral reach.

Table 1
Key factors and leading industries of the dual techno-economic paradigm

	Information and communications technology	Biotechnology
Recombination technology	Information technology	Genetic engineering
Support material	Electronic	Biological
Systemic characteristics of material support	Stable interface between discrete components of the technology (high modularization potential)	Unstable interface among discrete components of the technology (low modularization potential)
Key factor	Micro- (nano-) electronic devices that control physico-chemical processes	Genetically modified organisms that control biological processes
Motive branches	Electronics, information technology and telecommunications	Agents of biotechnological events (recombined DNA) and producers of active pharmaceutical ingredients, enzymes and other biological inputs
Vector branches	Productive assets (machinery), consumer durables (including vehicles, communications and appliances), services and digital platforms	Genetic selection of seeds, pharmaceutical industry, animal health, agricultural bioinputs, food ingredients, biopolymers and other industrial biotechnology

Source: Prepared by the authors.

We can thus postulate that the "key factor" of the dual paradigm consists of a technology to recombine and systematize information acting on a specific support material in order to control productive processes. In one case, electronic and IT devices (such as microprocessors and sensors) act on physico-chemical processes; in another, genetically modified organisms act as the means of production for biological processes, such as seeds in agriculture or cell lines that produce active ingredients for the pharmaceutical industry or animal health.

Once the key factor of the new paradigm has been defined, it is possible to rethink the distinction between the motive branch, which produces the key factor, and the vector branch, which uses that key factor to develop the products and processes that are emblematic of the new historical period. In the case of ICTs, motive branches produce the algorithms and electronic and IT devices (including microprocessors and sensors), while vector branches produce capital goods and consumer durables whose key innovation is electronic and IT-related (automated machinery and equipment, robots, sequencers, mobile telephones, computers and other smart devices). In view of the particular relationship between recombination technology and support material, the model of motive and vector branches in biotechnology takes a different form. In this case, the distinction occurs within the pharmaceutical industries and the agricultural and industrial input industries. It is based on a segmentation between, on the one hand, the properly biological phase, which is focused on the development and scaling up of genetically modified organisms that act as a motive branch (e.g. cell lines are genetically modified into those that create proteins, enzymes and biotechnological events), and, on the other hand, the conventional development phases of the product and production as such, that act as a vector branch (for instance, traditional phytomelioration, the preparation of medicines or veterinary products, fermentation processes in the food industry and biopolymers). That analytic distinction is not, however, incompatible with vertical integration models in which both functions are performed by the same company.

The following propositions can be made on the basis of these considerations.

- Proposition 1: There is no convergence between ICTs and biotechnology because in each case, the key innovation depends on a field of knowledge that covers distinct areas: in the first case, the information systems that act on an inert support (electromechanical systems), and in the second case, information systems that act on biological systems. These fields of knowledge are governed by autonomous laws, and they form the basis of distinct heuristics leading to divergent techno-productive trajectories.

- Proposition 2: Innovations in ICT are among the main causes of the restructuring of production in the contemporary global economic system, but that trend is not universal. In a group of industries, such as the pharmaceutical and agricultural input industries, the key innovation depends on a biotechnological knowledge base, and ICTs have only partial dominance. That suggests that the leading industries in contemporary capitalism are not responding to a single knowledge base, and that the definition and organizing principle of an endogenous core are not necessarily reducible to ICTs.

IV. Sectoral innovation trajectories in biotechnology-based industries

As we saw in the previous section, at each stage of history, a group of innovations emerge, the impacts of which shape the technological trends in the global economic system. Once a set of fundamental innovations has been consolidated (such as next-generation microprocessors, monoclonal antibodies or, more recently, messenger RNA), new technological trajectories are established involving incremental innovations, such as new product designs or applications or improvements to existing processes, with a corresponding impact on productivity. Various sectoral technological trajectories have emerged, either in connection with these fundamental innovations or as complements to previous trajectories.

From an evolutionary perspective, these sectoral technological trajectories involve a set of innovation heuristics and institutional mechanisms that enable the appropriation of the economic results of innovation (Dosi, 1982). In other words, sectoral trajectories define the direction of incremental innovations and determine the distribution of innovation-related windfall gains, on the basis of institutional appropriation mechanisms and standards. The definition of such institutional mechanisms, which are necessary to establish a sectoral innovation trajectory, requires agreement among the economic groups that dominate the industry at the global level and approval by regulatory bodies at the national level.

The dissemination of fundamental technology requires the establishment of a set of standards and ownership rights, yet the process for developing such agreements is not fully determined at the most general level of the current techno-economic paradigm; instead, it is sector- and country-specific. The mesoeconomic dimension, which refers to the space in which the relationships of competition and cooperation between a set of firms, research institutions and other organizations operating in a specific sector and territory are settled, is essential to understanding the nature and characteristics of these trajectories and the degrees of freedom that a nation State may have to establish a certain industrial and technological policy. In the following section, we address this issue in relation to biotechnology.

In the case of the innovation trajectories of biotechnology sectors, the disagreement over the maintenance or strengthening of oligopoly is defined in terms of both the ability to impose new products and processes (“dominant designs”) and the effectiveness of enforcing such productive dominance at the institutional level through the regulatory framework and intellectual property. A distinctive aspect of these industries is that the very definition of a new product is regulated, on the basis of whether a new event or discovery is patentable and requires approval to be marketable according to safety, effectiveness and environmental risk criteria established by the national regulatory authorities. This is characteristic of the mesoeconomic level, which revolves around innovation —and enabling institutional conditions— to deconstruct previous positions.

For example, with the emergence of biotechnology and, specifically, the development and early adoption of herbicide-resistant seeds, the chemical industry saw the possibility of extending its market reach to include agriculture. In other cases, however, such as insect-resistant innovations, biotechnological development would lead to the replacement of chemical products. With regard to new gene-editing technologies, there has been much disagreement over the definition of the regulatory standard for new developments, which has considerable implications for the dissemination of the innovation within the industry and for the distribution of the income generated by the innovation (Sztulwark and Girard, 2020). Within the framework of a paradigm shift from the chemical industry to the biological industry, without eliminating the former completely, foundational innovations advance and threaten acquired positions, which can only be made effective through State-led regulatory changes.

Similarly, in the biopharmaceutical industry, regulatory standards that impose clinical testing requirements for imitative products that are almost as rigorous as those imposed on the original innovations operate as a barrier both to the entry of new biotechnology companies into production and to the development of incremental innovations, which are what support sustained advances in productivity. In the same vein, intellectual property rights regimes with low originality requirements (inventive steps) and a broad scope of claims associated with those rights tend to limit the development of complementary innovations. This institutional setting, by encouraging the proliferation of innovations with patentable potential, is accelerating the entry of new biotechnology companies subject to "financial valorization", in association with successive biotechnology waves and changes in stock market values (Pisano, 2006; Lavarello, 2018).

During periods when fundamental technology is being consolidated, there is a reduction in the degree of freedom in the selection of techniques in adopting sectors and in the design of industrial policy in countries pursuing imitative strategies. Foundational innovations are consolidated and define the scope of expansion of adopting companies and countries in the narrow field of the established trajectories.

This situation is more nuanced in the case of biotechnology as, given the rapidly changing knowledge base, global foundational innovations do not achieve a high degree of consolidation and the situation remains "pre-paradigmatic", without a "dominant design" in each industry. Biotechnology is not characterized by the consolidation of a set of research and development heuristics; instead, successive waves of molecular biology revolutions have led to the development of new techniques, from genetic engineering in the 1970s to gene editing today, which have expanded the knowledge base and redefined existing patterns of innovation. The continued fluidity of research and development heuristics and the difficulty of consolidating a set of dominant designs and laboratory and manufacturing best practices have created an environment of considerable technological and regulatory uncertainty.

In this context, successive biotechnology waves offer accumulation opportunities for late-industrializing countries that identify regulatory gaps, such as high inventive step requirements for patents that do not block imitation, flexibility during pandemics and criteria for trade liberalization of biotechnology developments achieved through gene-editing techniques.

V. National capacity in the leading industries of the dual techno-economic paradigm

Having described the role of biotechnology in the context of the dual techno-economic paradigm, where ICT is only partially dominant, and advanced our understanding of the specificities of sectoral innovation trajectories in biotechnology-based industries, we now turn, in the present section, to a comparative analysis of current techno-productive capacities in Argentina in the industries in which key ICT and biotechnology innovations are being deployed (see table 2). To that end, we return to the distinction between the motive and vector branches which, together, constitute the leading industries of the dominant paradigm of this historical period.

Table 2
Argentina: productive capacity in the leading industries of the dual techno-economic paradigm

	Information and communications technology	Biotechnology
Motive branch	Information technology: - Niche technological capabilities in embedded software, with passive adoption of standards. - Relationship with technology infrastructure. - Low appropriation conditions with limited control of complementary assets.	Genetic engineering: - Capacity for early imitation of active pharmaceutical ingredients and for development of globally significant agro-biotechnological advances. - Continuous coordination with the science and technology infrastructure. - Emergence of research and development start-ups. - Average appropriation conditions at the national level, with growing internationalization.
	Electronics and telecommunications: - No capacity to design or manufacture essential electronic components (microprocessors) or telecommunications infrastructure (cloud, 5G). - Potential for the development of satellite technology and sensors.	Bioprocessing: - Capacity for imitative and incremental development and scale-up of active pharmaceutical ingredients for biological therapeutics, vaccines and diagnostic kits aligned with international best practices.
Vector branch	Assembly industry for electronic consumer durables: productivity levels and scale well below international levels but great versatility for the development of small batches with integrated systems for industrial and agricultural uses (precision agriculture). Services: applications for payment and marketing platforms.	- Genetic control of seeds at the regional and global levels. - National capacity to implement global regulatory standards for products and processes with productivity levels close to international levels. - Challenge: regional integration to consolidate the leap in scale in terms of production and business management at the regional level as a platform for global integration.

Source: Prepared by the authors.

Argentina has a number of long-established science and technology institutions, founded during the post-war period in response to the needs of import substitution industrialization. They include the National Scientific and Technical Research Council, which focuses on scientific production and evaluation, and the National Atomic Energy Commission, which coordinates science and production in the field of nuclear energy. As a result of its long tradition of excellence in scientific development, Argentina has a high proportion of researchers for a semi-industrialized country, at 5.14 researchers per 1,000 economically active people, compared with 2.23 in Latin America and the Caribbean as a whole (Ibero-American Network on Science and Technology Indicators, 2022). The country also has different organizations focused on applied research and the dissemination or provision of services to the productive sector, such as the National Institute for Agricultural Technology and the National Institute for Industrial Technology.

Argentina has unrealized potential in research and development, as evidenced by the low level of alignment between science and technology opportunities and their productive scaling. While Argentina has a high number of researchers, it underinvests in research and development, with such expenditure accounting for just 0.52% of GDP in 2020, compared with an average of 0.65% for Latin America and the Caribbean. The private sector's share of total research and development investment is also low by regional standards, at 23%, compared with 35% in Latin America and the Caribbean (Ibero-American Network on Science and Technology Indicators, 2022). This is due to the large number of small and medium-sized companies, which lack the scale to carry out research and development, and to the strengthening, since the 1990s, of a leading group of syndicates and subsidiaries of multinational companies that pursue a highly passive technology strategy, even in sectors with comparative advantages, such as the agrifood industry (Lavarello, 2004).

The unrealized potential of opportunities in the scientific sector is particularly significant in the area of biotechnology. As an example, at the National Scientific and Technical Research Council, the country's leading scientific research institution, the main area of specialization is biological and health science, which occupied 27.6% of the Council's researchers in 2022 (National Scientific and Technical Research Council, 2022). This specialization is also expressed by the relative share of scientists and engineers, which is more oriented towards life sciences than towards information technology-related fields of study.[8] This trend contrasts with what is happening in commercial research and development. Indeed, despite the fact that Argentine biotechnology companies have a research and development intensity (defined as research and development investment as a share of sales) that is more than double the national average, at 2.5% compared with 1.08%, biotechnology research and development accounted for just 4.3% of total research and development conducted by Argentine businesses in 2021 (Ministry of Science, Technology and Innovation, 2023).[9]

For its part, the local development of the motive and vector branches in ICT and biotechnology has been highly heterogeneous and influenced by sectoral promotion mechanisms that correspond to different layers of industrial and technological policy (Lavarello and Sarabia, 2017).

Owing to successive opening and financial liberalization processes since the mid-1970s, Argentina missed the opportunity to promote the local development of industries that drive ICT. Thus, at the same time that regional promotion mechanisms were being implemented for the development of a vector branch, the early development of business capabilities and an emerging infrastructure for the development of semiconductors and computers were curtailed.[10] This disconnect between the motive and vector branches can be seen most clearly in the specificities of Tierra del Fuego's regional regime, which is biased towards a small-scale consumer electronics industry, aimed at the domestic market and highly dependent on imports. Although Argentina has implemented an incentive regime for the software industry since the first decade of the new millennium, the types of product and sectoral participation remain limited to a few global suppliers of less complex programming phases and large companies that have managed to find a niche in regional payment and distribution platforms (Moncaut et al., 2021 and 2022). Nevertheless, there have been limited developments by a small number of manufacturing software suppliers, with emerging specialization in the design of integrated systems for the electronics industry, including for medical equipment and precision agriculture.

In contrast to the ICT sector, the existing knowledge base in molecular biology in Argentina made it possible to advance towards the establishment of a minimum number of companies with the potential to scale up and create a motive branch (Gutman and Lavarello, 2014; Lavarello et al., 2018). For example, an Argentine company succeeded in launching a biotechnological drug, recombinant interferon, just months after it was first produced in the United States (Katz and Bercovich, 1988). On the basis of this technological foundation, since the mid-1990s, the government has promoted a series of policies aimed at supporting biopharmaceutical companies.

During an early phase of the diffusion of the key innovation of genetic engineering, Argentina developed biotechnology as a motive branch by substituting new products for existing extractive products, enabling it to become an exporter in a market where regulatory thresholds were still low. With its accumulated experience in bioprocessing, Argentina was able to use this trajectory to move towards the early imitation of more complex second-generation drugs, such as monoclonal antibodies, and thus compete domestically against leading international companies. At the same time, some companies managed to find a niche for themselves by developing diagnostic kits for the regional market. The potential of this area became clear when, during the coronavirus disease (COVID-19) pandemic, an Argentine company took on the production for Latin America of the active pharmaceutical ingredient needed in

[8] The proportion of postgraduate students and researchers studying life sciences in Argentina is similar to the proportion in the United States, at 31.5% and 32%, respectively, of the total number of researchers and postgraduate students in all fields (Zukerfeld, 2014). The same is not true for computer science: in Argentina, computer science postgraduate students and researchers account for just 1% of the total, compared with 7% in the United States.

[9] The overall total refers to the companies included in the survey on research and development by the business sector in Argentina conducted by the Ministry of Science, Technology and Innovation, with data from 2021.

[10] Beginning in the 1960s, Argentina developed public research and development infrastructure associated with universities and defence-related centres, such as the Calculus Institute, the Institute of Scientific and Technical Research for the Armed Forces and the electronics laboratory at the Faculty of Engineering of the University of Buenos Aires. At the same time, key players contributed to pioneering developments in microelectronics, as in the case of the programmable scientific calculator developed by FATE Electrónica.

the global value chain to manufacture a viral vector vaccine, which led to the company's establishment as a global supplier of contract manufacturing and design services. Meanwhile, collaboration between a public university and a local biotechnology company led to the integrated development and manufacture of an alternative COVID-19 vaccine.

In parallel to these developments in bioprocesses, Argentina has research, development and production capabilities in the area of biotechnology. They include the development of capabilities linked to new messenger RNA vaccine technology that could open the door to a whole range of new niche therapeutics, as well as developments in gene editing for human health. A local group has built a plant that is one of two regional sites selected by the World Health Organization to produce mRNA vaccines (the other is in Brazil). Meanwhile, public-private collaboration has advanced the development of new waves of gene therapy using clustered regularly interspaced short palindromic repeats technology.[11]

Significantly, such opportunities have made it possible for Argentine business groups to develop complementary projects with the animal health industry, replicating the coherent diversification strategies of leading companies in the life sciences industry, where progress in animal health can be the first step towards advancing to the higher regulatory thresholds for human health. For example, the development of cancer vaccines in small animals in partnership with Cuban research and development institutes has laid the groundwork for a new way forward in which cancer becomes a chronic disease like arthritis.

This context also made it possible to develop bioprocessing capabilities and imitative biopharmaceuticals. A minimum threshold of experience in bioprocessing has been reached, making Argentina one of the few developing countries to produce active pharmaceutical ingredients, building on a high level of vertical integration with the vector branch of biotech drugs. These capabilities have enabled Argentina to achieve the thresholds of experience and knowledge necessary for the early adoption of new waves of biotechnology, such as messenger RNA and gene editing.

Argentina has also adopted key innovations in global agro-biotechnology. Early on, it established a regulatory framework for the approval of genetically modified crops and created complementary capacities, including in the seed, agricultural machinery and agrochemical industries, which enabled the rapid adoption of innovations in the framework of the new model of agricultural production (Bisang, 2022; Sztulwark, 2012). Through the rapid adoption of a mostly imported technological package, Argentina built a solid capacity to produce primary goods and agricultural products with some degree of industrial transformation.

Although Argentina remains a technology adopter and its knowledge production systems lag behind those of developed countries, the country has a scientific and technological base capable of producing biotechnological developments of global importance, including in the area of gene editing (Sztulwark et al., 2023; Feingold et al., 2018). The most technologically significant examples are transgenic innovations developed by national companies (such as drought-tolerant wheat and soybean and virus-resistant potato plants) and advanced gene-editing innovations, such as a project on potato varieties led by the National Institute for Agricultural Technology and another on herbicide-tolerant soybean crops led by a private company with international funding.

In recent years, an entrepreneurial base has emerged, with some companies reaching global markets (both in the motive and vector branches) thanks to new ventures, the development of which has been associated with the promotion of science-based accelerators and new venture capital financing structures (Sztulwark et al., 2023; Gonzalo et al., 2023; Stubrin, 2022). Another important element is the momentum of the agricultural bioinputs sector, particularly in the area of inoculants. These actors and processes, in turn, are part of regional innovation dynamics, including the growing public-private network in the Province of Santa Fe (O'Farrell et al., 2022). Lastly, at the institutional level, the country has advanced regulatory capabilities (Whelan et al., 2020).

[11] For example, a cooperation agreement between the Favaloro Foundation University Hospital and the National University of Quilmes led to progress in the development of gene therapy for the treatment of COVID-19.

In addition to the country's biotechnological innovation capabilities in the agricultural inputs, human health and animal health industries, there are several national companies with the capacity to develop and produce biological inputs for the manufacturing industry and a growing group of science-focused businesses carrying out biotechnology research and development (Ministry of Science, Technology and Innovation, 2023). This productive capacity in the area of biotechnology —the development of which was underpinned by coordination between public research and development laboratories and local companies and by substantial science and technology infrastructure, centred around the National Scientific and Technical Research Council— served as the basis for the emerging dominance of the motive branches of these industries.

VI. Limits and opportunities for the development of a biotechnology-based endogenous core in Argentina

As set out in the present paper, the historical global change under way is linked to the development of a dual techno-economic paradigm with a dominant ICT core and another, more limited, biotechnology core. Fundamental innovations tend to be deployed in related industries based on production (motive branch) and productive use (vector branch) of a key factor: electronic computing devices in the case of ICT and genetically modified organisms in the case of biotechnology. Accordingly, the definition of an endogenous core for Argentina, in reference to the strategic orientation of investment in technology and production, should not necessarily be limited to ICT.

Indeed, given the historical trajectory of the country in the area of technological production, and its relationship with changes in the international landscape, there are indications that opportunities for structural change could be greater in the field of biotechnology than in the field of ICT. Such indications deserve more attention and discussion. The observations presented in this paper on the country's relative strengths in the biotechnology vector branches (primarily biopharmaceuticals and agricultural inputs), compared with the ICT field (electronics), and the development of software and digital devices), could be a starting point for the deployment of the motive branch, beginning with the establishment of better links with the scientific system, which has traditionally been stronger in the biological sciences than in computer science and electronics. The strategic integration of all these elements could help to establish an endogenous biotechnology core in Argentina, with a focus on the agricultural and health sectors.

Once the sectoral pivots of the endogenous core have been defined, a strategy of this type needs to coordinate activities aimed at consolidating the motive branches and linking them to existing vector branches, with a view to expanding beyond the domestic market. Expanding to the rest of Latin America, in particular to Brazil, is vital to ensuring economic sustainability. However, an initiative of this nature requires significant expenditure on exploratory research and development, which not every company can afford. The first step is for industrial policy to become innovation policy through the strengthening and reconfiguration of the existing scientific and technological infrastructure and through the establishment of business goals and requirements in the areas of intellectual property and profit-sharing from innovation. Any industrial policy requires the establishment of large-scale productive units (a joint venture or a network of companies coordinated by a government agency) that are capable of reaching the thresholds necessary to rise up technologically in the global system and that have the potential to create new niches for themselves in the emerging trajectory and bolster the national production framework.

The main obstacle is clearly not a technical one. Public intervention should not be seen as an external factor resulting from good planning, since the dynamics of the stakeholders, both public and private, do not precede the strategy, but are, in fact, a product of the process of change itself, at least in part. This, in turn, is related to the specificity of the economic power structure and its capacity to veto changes in the existing pattern of specialization, protecting rent-seeking segments with low innovation. This translates into strong actions aimed at disrupting the industrial policy actions of a State, resulting in a war of positions between those wishing to preserve the old structure and those seeking to support the dynamic sectors. A project of this nature requires, first, the definition of an endogenous core that acts as a mobilizing force for existing resources and capacities and is supported by a cohesive and committed group of stakeholders and, second, influence over social groups with contradictory interests. In this political landscape of technological and industrial policy, there is the possibility of advancing towards structural change in Argentina.

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