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CHAPTER 1

BRAZILIAN SCIENTIFIC AND TECHNOLOGICAL PERFORMANCE

1 INTRODUCTION
A country’s scientific and technological performance can be examined from various perspectives, from its researchers’ scientific output to its businesses’ innovative performance. Thus, in this chapter, we introduce several indicators that will allow us to define how far science and technology (S&T) have advanced in Brazil in recent years. The data used reflect the volume and quality of national scientific output, the number of innovative companies, the number of patents filed by these companies, and other indicators of business success.

Scientific and technological performance results from several factors or forces that, when combined, determine a country’s level of scientific and technological advancement. It is hard to imagine that a country with a poor educational system – in scope or quality – would have the necessary conditions to be scientifically competitive. In addition to excellence in education, high-quality science also requires adequate infrastructure and sufficient, stable funding. Innovative companies, in turn, demand a favorable economic environment that fosters their development and growth, as well as access to state-of-the-art technologies to make them competitive and even more innovative. All of these factors, and the extent to which they influence the performance of a country will be examined later. In this chapter, the focus is on the outcome of this set of forces: our scientific and technological performance.

2 SCIENTIFIC OUTPUT
For a long time, the linear model – in which scientific research and invention always precede innovation – has not been the paradigm for analyzing the innovative process. Researchers recognize that the dynamic of innovation is much more complex, full of back-and-forth iteration, and not always preceded by a scientific discovery.

However, it is also true that no country becomes more innovative and competitive without a strong scientific base capable of producing not only skilled human capital but also knowledge that can facilitate the innovation process. Therefore, the status of knowledge production and the importance and impact
of knowledge produced are key indicators for evaluating Brazil’s performance in the area of S&T.

The most widely used indicator for quantitatively evaluating the scientific production of a country is the number of publications in internationally indexed journals. In the Brazilian case, the country’s scientific output has significantly grown since the mid-1990s, with a noticeable acceleration starting in the mid-2000s. Two indicators in chart 1 show this growth. The first indicator is the number of articles per inhabitant, where Brazil’s output grew from a little more than twenty articles per million inhabitants in the early 1990s to 182 articles in 2013, faster growth than the rest of the world, which allowed Brazil to surpass the global average. This growth was also reflected in the increase in Brazilian participation in international publications, which rose from 0.7% to almost 3% in the same period.

Several fields of Brazilian scientific production stand out. In these areas, Brazilian participation in international publications is higher than the average of 3%, which shows the country’s advantage compared to other countries in these specific fields. dentistry, although it does not correspond to a significant share of the Brazilian scientific production (about 2%) or of the world (0.3%), is one of the fields in which Brazil most stands out from a comparative perspective:
Brazil accounts for 16% of global scientific production in dentistry. Other fields in which Brazil shows a comparative advantage (chart 2) are: veterinary medicine (with 9.4% of global scientific production); life and agrarian sciences (6.7%); nursing (4.7%) and microbiology and immunology (3.9%).

CHART 2
Brazilian participation in global scientific output, per area of knowledge (2012)

No one denies that the influence of scientific research on the production of new technologies has grown substantially over the last few decades. However, some fields are more linked to recent technological trends than others. From this perspective, the fields in which a country acquires greater scientific competencies do not exert a neutral impact upon innovation activities. A recent study by Brazilian researchers confirms this finding, based on an analysis of scientific papers cited in patents filed at the United States Patent and Trademark Office (USPTO) (Ribeiro et al., 2010). The authors highlight the growing importance of certain scientific fields – including electrical engineering, chemistry, and chemical engineering – in patenting activities in several countries. In regards to the Brazilian case, the study also shows a certain disconnect between the areas in which the country is more competitive and those that are in greatest demand for innovation activities in the rest of the world.

The clearest example of this disconnect is perhaps the small participation of the engineering fields in both scientific production and human resources training in Brazil, compared to the importance of this field to the development of innovation in the world. In Brazil, engineering represents just over 4% of scientific production. Narin, Hamilton, and Olivastro (1997) have already highlighted this growing relationship with the United States.
production, compared to more than 10% of global scientific output. This gap, which has been identified by several authors, is sometimes attributed to the poor quality of mathematics education at both elementary and secondary school levels in Brazil, or to the low demand for engineers in the Brazilian productive sector.

Another field of vital importance that has been pushing the frontier of innovation in the contemporary world is information technology (IT). Economists at Massachusetts Institute of Technology (MIT) have compared the potential effects of current advances in IT to those caused by the steam engine (Brynjolfsson and McAfee, 2014). The invention of the steam engine, by boosting the physical strength of humans, created the conditions for the emergence of modern industry, for population growth, and for the increase in people’s life expectancy. According to the authors, IT will boost not physical strength, but the intellectual strength of humans, and its effects on humanity could be as revolutionary as the steam engine and the industrial revolution.

Indeed, the exponential growth in computers’ processing capacity has allowed the birth of new tools and applications using, for example, artificial intelligence. New ITs also promise to automatize a series of activities that today still rely on human intervention. The use of robots in industrial activities is expected to grow significantly in the coming years, and the greatest limitation for its dissemination will not lie in technological constraints, but rather in the cost of such equipment compared to the cost of labor. The replacement of people by machines will only be economically viable once their relative price decreases further compared to the cost of labor, which is expected to happen gradually and only for some technologies.

Despite its relevance to humanity, computer science accounts for merely 2.9% of Brazilian scientific output, and for less than 5% of global output. In countries such as the United States, this field corresponds to almost 10% of the country’s scientific production. In China or Germany, this field’s contribution is even higher.

In addition to the low scientific production in several crucial fields, a handful of scholars have raised concerns regarding the quality and impact of Brazil’s scientific output. However, assessing scientific production from the perspective of its impact and its quality is even harder than doing so based on volume. One relevant indicator of academic impact is the influence an article has on other researchers, within the country and abroad, which can be gleaned from the number of citations it receives. The more cited an article is, the more influential the work

2. For more details, see Frischtak and Davies (2015), for example.
3. Cruz (2009), shows, among other things, the low number of scientists and engineers working for Brazilian companies.
is and the higher its academic impact – which also suggests the work is of high quality. However, the qualitative evolution of Brazilian science has not proven to be as noteworthy as its quantitative increase, and the international impact of what Brazil produces is still small (Zago, 2011). In fact, Brazil accounted for just 1.67% of the citations of scientific articles worldwide in 2015, much less than its share of global scientific production. The growth in citations observed from the early 1990’s to 2015 was roughly threefold, and although significant, it was also lower than the increase in the number of publications.

In spite of these concerns, and having had better quantitative performance, Brazil is not at the bottom of the citations ranking. According to Scopus citation database, the country ranks 23rd on the h-index. This index was created to measure the impact of a country’s or researcher’s scientific output: it is defined as the number of articles with at least that number of citations. According to the Scopus database, Brazil’s h-index is 461, meaning that the country has 461 articles with at least 461 citations. This places Brazil, for example, ahead of the other Latin American countries.

3 INNOVATION AND BUSINESS INVESTMENT

Innovation is the creation of new products or processes, or the significant improvement of existing products and processes. The concept embodies several meanings. The most important is that innovation, whether a product or a process, needs to be introduced in the market in order to be an innovation. More specifically, an invention or a new technology is not an innovation until it becomes a product (or process) introduced to the market by a company. Therefore, the economic agent responsible for developing an innovation is the company, not an individual or a research institution. The second implicit, important meaning is related to novelty. An innovation need not be something completely new. On the contrary, most innovations are incremental: enhancements or improvements to existing technologies and products.

Although Brazil has made several significant advances in terms of scientific output, in terms of business innovation the results of the last few years have not been as impressive. Two indicators are critical to this analysis: the number of companies that create new products and processes (innovation) and the amount invested by these companies to develop these innovations.

In order to innovate, businesses invest in people, equipment, and research that allow the development of more efficient products and processes. Business investment in research and development (R&D), from the company’s perspective, is a factor of production of the innovative process. From the country’s perspective, however, it is a valuable indicator of the outcome of its policies. Effectively, several
countries’ innovation policies have aimed at increasing business investment in R&D, exactly because such investment has the potential to boost both innovation and economic competitiveness. In addition, private sector investment in R&D is also necessary for businesses to make use of technologies developed externally.

Brazil invests 1.27% of its gross domestic product (GDP) in R&D, including government and private sector spending. This is far below the average for Organisation for Economic Co-operation and Development (OECD) countries, which is 2.38% of GDP, but it is higher than other Latin American countries like Mexico and Argentina, and even countries like Spain or Portugal.

This percentage reflects the sum of investments made by the government and by companies, and changing its composition is perhaps one of the greatest challenges of the country. Although total R&D investments in Brazil are not considered low, corporate investments, which should be encouraged by public policies, are lower than in a number of other countries, and have remained relatively stable over time. In Brazil, corporations account for just under half of all R&D investment, totaling about 0.6% of GDP in 2014. This proportion is usually higher in developed countries. Using the OECD average as an example, in those countries the private sector accounts for almost 70% of total investment in R&D, or about 1.63% of GDP.

Chart 3 shows the evolution of corporate investment in R&D in several countries, between 2003 and 2014. Notice that, with the exception of Canada, Argentina and Mexico, all other countries, including Brazil, showed a trend of growth in all years except in 2011, due to the impact of the international crisis on the level of investment in several countries. Thus, although Brazil has slightly increased private sector investment in R&D in recent years, the country remains roughly in the same place relative to the rest of the world. Countries such as Spain and Portugal, which had shown levels of business investment in R&D lower than Brazil’s at the beginning of the series, managed to see serious gains in this indicator and their companies are currently investing at a volume almost similar to the level of investment by Brazilian companies.

5. Based on data from the MTIC available at: <http://www.mctic.gov.br/mctic/opencms/indicadores/>. The year 2017 has radically changed this situation, due to the fiscal crisis and the reduction in public investments in S&T. This issue will be addressed later on.

It is also important to emphasize that the increase in private sector investment in Brazil, from 0.54% of GDP in 2011 to 0.6% in 2014 is not sustained growth. In fact, this was purely circumstantial growth caused by an increase in R&D investments in the telecommunications sector. In fact, the sector virtually quadrupled its investments, going from just over R$ 1 billion in 2011 to more than R$ 4 billion in 2014. Researchers at Ipea suggested that, without this increase, business investment in R&D would have remained steady at 0.54% of GDP (De Negri et al., 2016). Telecommunication experts argue that this observed increase in investment was linked to the World Cup held in Brazil in 2014, since companies had to make a number of investments to modernize the country’s telecommunications infrastructure. In short, considering its source, the growth in 2014 was not sustainable, and a more credible number for R&D investment by Brazilian businesses is the figure observed in 2011, which was 0.54% of GDP. Taken together, this suggests that private sector investment in R&D has remained stable in recent years, unlike the data collected on scientific output.

This information comes from the Research for Technological Innovation (Pesquisa de Inovação – Pintec) series conducted by the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística – IBGE), which is the principal source of data on innovation in the Brazilian economy. The institute collects data from a sample of more than 17,000 companies, representing all of Brazilian industry and service providers, looking for information
on corporate investment in R&D, whether the companies are innovative, and the major obstacles to and results of innovation.

In the first edition of the PINTEC study in 2000, 32% of industrial enterprises said they had innovated (i.e., introduced new products or processes) within the three-year period prior to the survey. This number rose during the period from 2006 to 2008, but then decreased in the latest edition of the survey, closing the series at just over 36%. This number refers to all the businesses that created or adopted new technologies, even those already commercialized by other businesses. However, when the question was whether the company had created an innovation that was new to the Brazilian market, that is, a de facto innovation, that number dropped to below 4% and has remained steady for the last fifteen years. As an example, the automaker that first introduced the backup camera in a car came up with a market innovation. The other automobile manufactures that adopted this technology afterwards are also innovative, but they do not belong to the select group of companies that have brought an innovative new product to the market.

The fact that only 4% of Brazilian industries have developed genuinely groundbreaking products or processes for the domestic market, and that this indicator has remained steady, is a clear indication of Brazil’s slow progress in terms of private sector innovation. This does not mean, however, that the country does not have a diversified productive sector capable of generating innovation and investing in research to a degree that surpasses other Latin American countries and even approaches that of richer countries.

4 TECHNOLOGIES PROTECTED BY PATENTS

A patent is not a required outcome of an innovation, but rather just one of the many mechanisms businesses use to protect their creations. However, growth in the number of patents is strongly related to growth in the production of new technologies.

Ultimately, companies innovate and protect their creations in order to earn larger profits than their competitors. These extraordinary profits are what make companies allocate part of their budgets to researching new products, exploring new markets that could increase future revenues, or developing processes that reduce costs. If such innovations were not protected, imitators could quickly begin to manufacture the product developed by the original company and thereby take some of its profits. Such an outcome would, obviously discourage corporate investments in an activity like innovation, which is both risky and likely to go wrong. Naturally, the question of how to achieve an optimal level of protection to ensure maximum returns to society (i.e., better and cheaper products
and services) has been under intense debate. Some authors argue that excessive protection could stifle innovation rather than encourage it. Nonetheless, there is some consensus among experts that some form of protection for innovators is necessary to foster more innovation.

In certain markets, innovative companies can choose to protect their innovations by keeping their manufacturing process a secret. This would be the case for a formulation or a production method that does not pose a major technological challenge, like the Coca-Cola recipe or a specific algorithm. In such instances, simply gaining this piece of information would allow the product to be replicated. Since a patent is public and temporary, with this piece of information any company interested in manufacturing the product could do so after the patent expires. Therefore, many companies maintain secrecy in order to extend the duration of their full rights over a product or process.

Patents are, however, an essential method of protection for most innovations and several sectors, such as the pharmaceutical industry, rely heavily on patents. The number of patents filed at Brazil’s National Institute of Industrial Property (INPI) rose from about 20,000 in the year 2000 to just over 30,000 in 2016. This 50% increase was lower than the international average, with patent applications more than doubling worldwide during the same period.

In Brazil, as in other developing countries, the majority of patents (80%) submitted to National Patent Office (Instituto Nacional de Propriedade Industrial – INPI) come from non-residents, that is, either from people who do not live in Brazil, or from companies that are not based in the country. In developed countries, the distribution of patents among residents and non-residents tends to be more equal and, in many cases (such as Germany), the majority of patent owners are residents. According to the World Intellectual Property Organization (WIPO), worldwide, residents account for almost two-thirds of patent requests filed in countries.

In Brazil, among the 20% of patents submitted by residents, half are filed by individuals (independent inventors) and the other half are filed by local companies or research institutions. It is reasonable to assume that a patent filed by an independent inventor is likely to be less economically viable than patents filed by companies. In Brazil, among the 10% of patents held by residents who are not independent inventors, 7% are filed by companies and 3% are filed by

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8. In this sense, a patent application filed with INPI by a subsidiary of a foreign company located in Brazil would be considered as a resident’s filing. On the other hand, if the parent branch of that same company, located abroad, had applied for the patent, it would be regarded as a non-resident filing.
universities and research institutions. The increase in the participation of such organizations in patenting activity is perhaps the most significant development in patenting activities in Brazil in recent years (in 2000, they accounted for just 0.38% of filed patents; see the section in the third chapter on the interaction between science, innovation and companies).

The fact that only 7% of patents were submitted to INPI by domestic companies reflects one of the main weaknesses of our innovation system: the low level of innovation and patenting by Brazilian companies.

From the perspective of Brazilian participation in international patents, there has not been a significant change in recent years. We can use the number of patents filed by Brazilian companies, institutions, or individuals with the United States patent office as a parameter for this analysis. From 2000 to 2015, the number of Brazilian patents rose from about 100 to just over 300, a growth that seems substantial at first glance. However, Brazil’s share is negligible compared to the almost 10,000 patents filed in the United States by China each year.

Yet again, Brazil remains at an intermediate position. The nearly 4,000 patents granted over the years by the USPTO to Brazil places us ahead of all other Latin American countries, Portugal, and many developing countries. On the other hand, we were already at this point at the beginning of the decade, and we continue to rank below the other BRICS nations (Brazil, Russia, India and China, including South Africa) and European countries such as Ireland or Spain.
5 EXPORTING TECHNOLOGY-INTENSIVE PRODUCTS

There is a correlation between the technological development of a country and exports that are more diversified and more knowledge-intensive. The development, production, and export of such products – including computers, electronics, pharmaceuticals, communication devices, and airplanes – rely heavily on innovation. Thus, a country’s international competitiveness relative to these products reflects, to some extent, its ability to develop new technologies.

This does not mean that other sectors, such as agriculture, do not need or do not incorporate knowledge and innovation. It does mean, however, that the intensity of knowledge required by a person in charge of building an airplane is substantially higher than that of someone in charge of cultivating soybeans. The latter may be an intensive consumer of technologies embedded in machinery and equipment and in the inputs used, but is not necessarily a technology developer.

This correlation also does not mean that all countries with few technology-intensive exports are exclusively technology consumers, unable to produce knowledge and innovations. One example is Australia, a major exporter of commodities, where tech-intensive products account for a small fraction of exports. In spite of this, Australian industry accounts for more than 25% of the country’s GDP, and the country invests more than 2% of its GDP in R&D – of which 1.2% is private sector investment. In addition, the country ranks among the world leaders in terms of publications and citations of scientific articles.

Yet aside from a few exceptions, the possession of scientific and technical abilities allows a country to produce and export more complex goods. For this reason, the participation of more complex products in the export agenda may be regarded as a result and an indication of the technological development of a country.

In recent years, the increase in price of several mineral and agricultural commodities has reversed the previous trend of growing participation of high-tech products in global exports. From 2000 to 2014, such participation dropped from 14.6% to 9% of total exports. This was true for many countries, with a few exceptions like China and India (chart 5). In general, looking at the behavior of this indicator among countries, there is a correlation with the indicators for private sector investment in R&D, patenting, and even scientific output. Most technologically-advanced countries tend to show a greater proportion of high-tech products in their exports.
Once again, in this area, Brazil occupies an intermediary position, not too far from developed countries, and ahead of many developing countries. However, Brazil had one of the most pronounced decreases in this indicator. Technology-intensive exports accounted for about 9% of total Brazilian exports in 2000, but just 3% in 2014. The increased importance of commodities to Brazilian exports, to the detriment of other goods such as technology-intensive items, reflects not only price variations, but also the fragile and declining competitiveness of the country for products requiring greater technological effort.

6 THE USE OF NEW TECHNOLOGIES

The effect of new technologies on economic growth depends heavily on the level of diffusion of these technologies across society and, in particular, the producers of goods and services. The basic technologies required for mobile smartphones and Internet access, for instance, existed long before they became actual products and were widely adopted. Many existing technologies, such as self-driving cars or certain types of robots, have not been widely adopted either because they demand specific regulations, are not economically viable, or simply because society still does not know how to employ them productively.
In developing countries, where labor is inexpensive, new technologies usually take longer to become economically viable. In these countries, it is cheaper to hire workers to do tasks that could be done by modern and expensive machines. Yet contrary to what some neo-Luddites might think, refusing to adopt new technologies might preserve jobs in the short run, but in the long run it contributes to maintaining technological and income gaps in comparison to richer countries.

This occurs because a country’s quickness in learning about and beginning to use foreign innovative technologies is also a crucial factor behind productivity and income growth. Moreover, since incremental innovation is the predominant type of innovation, the ability to innovate depends heavily on the ability to use available technologies in the best way possible.

A recent study (Comin and Hobijn, 2004), using unpublished information on the diffusion of technologies between countries, showed that the speed of this diffusion is positively related to several factors, most notably: i) human capital (education); ii) degree of openness of a country; and iii) adoption of previous technologies. In other words, in order to be able to use new technologies, a country first needs qualified professionals who understand their workings and can operate them. Second, countries need to be open to the acquisition of technologies (which are often embedded in machinery and equipment) produced in other countries. Lastly, the prior adoption of a precursor technology aids the adoption of a more advanced technology.

For a country far from the technological frontier, access to state-of-the-art technology is generally gained through routes such as licensing technologies, buying imported goods, paying royalties on the use of imported technologies, R&D procurement, and technical assistance. Just as it exports very little of the technology incorporated in its products, Brazil is also a very closed market for imports of goods, knowledge, and technologies produced overseas. In the case of technology, the evidence is in Brazil’s technology balance of payments with the rest of the world, which is much lower than that of many other countries, including Argentina, South Africa, Russia, and almost all developed countries (Zuniga et al. 2016).

Chart 6 shows another indicator of technological exchanges between Brazil and other countries. It shows payments made by Brazilian companies to foreign entities for the use of intellectual property, which account for about 0.3% of GDP. This number is higher than that of other developing countries such as Mexico and China. Still, it is lower than the OECD average and that of several other developing countries. The horizontal lines on the graph, in turn, represent the goods imported as a percentage of total imports from the country. Yet again,
by this measure, Brazil accesses fewer foreign technologies than most other selected countries. Moreover, Brazil has one of the lowest trade flows relative to GDP compared to practically every country in the world. According to World Bank data, the sum of Brazil’s imports and exports accounts for 25% of its GDP (see chart 2, in the section on Competition, openness, and innovation in chapter 4), a number similar to that of Argentina and much lower than almost all other countries for which the World Bank collects data.¹⁰

Expanding the use of technology can also be a driving factor in a country’s capacity to produce cutting-edge technology. There is no opposition between these two activities; in fact, they are complementary. In S&T, isolation always leads to a worse outcome than integration. It is neither reasonable nor feasible to try on your own to develop knowledge and technologies that are already available elsewhere, because these technologies will quickly become obsolete. The technologies of the future have yet to be produced, but in many cases, they

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¹⁰ This excludes a few countries, such as North Korea.
emerge from the improvement of existing technologies. If a country does not use the latest technology, it is less likely to produce the next generation.

7 SUMMARY
What these indicators show, in general, is that Brazil is far from being a backward country from a scientific and technological perspective. This is the “glass half-full” part. The country sits at an intermediate position on practically all indicators of production and use of knowledge and new technologies. On some indicators, the country’s situation is better than several European countries, including Portugal or Spain; and Brazil is ahead of every other Latin American country almost across the board. Our worst performance is in patent filing, whether in Brazil or abroad.

The “glass half-empty” part, however, concerns Brazil’s evolution in recent years. Despite a relatively strong period of economic growth in the 2000s, considering our historic patterns, the country did not significantly improve its scientific and technological performance. These areas have improved in absolute terms, obviously. However, from a relative perspective, Brazil’s evolution was slower than practically all relevant countries, even developed countries, which tend to have slower growth rates compared to developing countries such as Brazil. For this reason, Brazil has dropped further behind relative to the rest of the world.

The one performance area where Brazil advanced faster than the rest of the world was scientific output. Our scientists today are more actively engaged in international publications than in the 1990s, and this growth has been sustained and constant over the last two decades. Brazil first approached and, in recent years, surpassed the global average for number of publications per inhabitant. This is encouraging news, despite the enormous challenges that lie ahead, because good science is the foundation for an innovative country.