Fernanda De Negri

New Pathways for Innovation in Brazil

Wilson Center
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PREFACE

Innovation – that is, the ability to add value to products and processes resulting from new knowledge acquired through scientific research – does not rely on funding and facilities alone. It also depends on "a stimulating and dynamic environment that allows prevailing competences to develop and thrive accordingly," without the limitations imposed by efficiency-inhibiting policies, such as local content restrictions, "which block the country's access to state-of-the-art technologies." This was the main conclusion of the 6th Congressional Study Missions on Innovation organized by the Brazil Institute of Woodrow Wilson International Center for Scholars and Brazilian Research-based Pharmaceutical Manufacturers Association (Associação da Indústria Farmacêutica de Pesquisa – Interfarma) between 2011 and 2017.

This important message on innovation is examined in detail in the following pages, written by economist Fernanda De Negri, a specialist in the subject of innovation at the Institute of Applied Economic Research (Ipea, and informed by the presentations and debates held at the Massachusetts Institute of Technology (MIT) in April 2017 as part of the sixth Congressional Study Mission. Over the years, the Study Missions have brought more than sixty Members of Brazil's National Congress to universities, research centers, and pharmaceutical companies in the United States and in England.

In all of these missions, Brazilian entrepreneurs who achieved success outside of their home country highlighted the low volume and the slow processes of health research in Brazil, both stemming from the lack of a dynamic and creative innovation ecosystem that, in turn, is an indication of the low degree of economic openness in Brazil. According to these entrepreneurs, Brazil should (as it has started to do) abandon the tradition of giving political appointees leadership of technical institutions such as the Brazilian Health Regulatory Agency (Agência Nacional de Vigilância Sanitária – Anvisa), and instead use selection committees to find professionals well-prepared to take on these roles, as is already the case with several highly successful institutions, such as Aeronautics Technological Institute (Instituto Tecnológico de Aeronáutica – ITA).

The interactions between Members of Congress and young Brazilian researchers during these missions were particularly relevant to the future of innovation in the country, especially in Boston Cambridge during the 2017 mission, when senators and congressmen met with a dozen doctoral students at MIT. As De Negri writes in her introduction, "While expressing their desire to return to Brazil and to contribute to local scientific production, [student researchers] also expressed concerns about their future in the country. Everyone shared the perception that the possibilities of a professional career in Brazil are very limited." Changing this perception, by adopting public policies that make Brazil more attractive to the talented scientists graduating from its universities, is a challenge that the nation has to face.

As De Negri's excellent work notes, meeting this challenge requires, among other measures, collaboration and productive exchange. The Wilson Center's Brazil Institute is grateful to the Brazil Institute of Kings College in London, the Institute of the Americas at the University of California San Diego, the Lemann Center at Stanford University, and the Brazil Program at MIT, for their support and partnership in hosting the Study Missions from 2011-2017.

Paulo Sotero
Director, Brazil Institute, Woodrow Wilson International Center for Scholars

FOREWORD

Brazil has a long history of neglecting innovation. Initially, this was due to thinking that the country would not depend on it, following centuries of economic success based on raw materials. More recently, this neglect has been due to a magical belief in the powers of a large internal market. This may be more than a strategic error. It seems to have something to do with a general belief in Brazil that the future would always happen without preparing for it or pursuing it.

Therefore, we have never taken on the duty of building the nation through education. We have never embraced risk and entrepreneurship as fundamental, if not unique, ways of achieving business success. A vast majority of domestic companies has always turned first to public financing rather than obsessively pursuing innovative processes and products. As a result, scientists and researchers are neither idolized nor supported. We regard them as strange figures who usually rank below scholars at universities, and are treated as representatives of some exotic entity in their private life.

The public sector, of course, has contributed greatly to creating an unfavorable environment. It does not view innovation as the center of thoughtful, effective, and long-lasting public policies. Instead, it hinders innovation wherever it can, by creating more than a dozen ministries, secretaries, and agencies on which the innovator must rely, enforcing regulations that make researchers wonder what they have done to run into so many difficulties, or by the lack of strong incentives for those who take financial risks in their ventures, which are crucial for innovation.

Brazil is a curious country. Despite all of this, we have gained some capacity for innovation, albeit through the isolated actions of islands of competence and resistance. Nonetheless, we produce papers, export scientists, and have earned international respect in specific areas of innovation. That is, the worst aspect of our lack of innovation is the fact that it does not result from inability, but from squandering: a terrible squandering of potential that otherwise could, against all the odds, allow us to progress reasonably if innovation were adopted as a national project and necessity.

This book, by the distinguished and respected Fernanda De Negri, discusses these two opposing and coexisting truths: the Brazil that we could become, given the small advances already achieved and our enormous unfulfilled potential; and the Brazil that fails to organize itself and assume its role as an innovative country.

The author takes us on an instructive and balanced journey through the constraints on innovation, illustrating our challenges and, at the same time, our possibilities. She serves us a half-sweet, half-bitter cup of coffee in exposing our mistakes and in hoping for a reversal of this reality.

Interfarma, an entity devoted to ethics and innovation in health, is pleased to contribute, in a permanent way, through events, publications and study abroad missions, to the debate on innovation.

It is our hope that this publication will remind us, in times of change, that innovation is no longer optional, a subject that Brazil can either take up or ignore without serious consequences. Innovation in these times of technological revolution has assumed another characteristic: it will determine our future, and it will define the role we play as a country and as society.

May the work of Fernanda De Negri urge us to not lose hope, and remind us that much is needed in order to achieve it, and urgently.

Antônio Britto
Former Chief Executive Officer (CEO) of Interfarma

INTRODUCTION

This document is the fruit of intense and worthwhile debates held in early April 2017 among Brazilian lawmakers, business leaders, researchers, and entrepreneurs in Boston and Washington at institutions such as the Massachusetts Institute of Technology (MIT), Harvard University, and George Washington University, among others. This was the sixth of a series of missions, organized by the Brazil Institute of the Wilson Center in partnership with the Brazilian Research-based Pharmaceutical Manufacturers Association (Associação da Indústria Farmacêutica de Pesquisa – Interfarma), whose main objective was to debate ways to stimulate the innovation process in Brazil with Brazilian and foreign specialists, to identify the main bottlenecks and options for overcoming them.

The question that underpinned the three days of presentations and debates was: What does the Brazilian innovation ecosystem lack? It was this question that guided all the experts, researchers, and entrepreneurs, whose presentations sought to provide elements that might help answer it. The introductory presentation was the golden thread of this book. It examined international experiences, including many lessons Brazil could draw on to improve the environment for innovation. This presentation pointed out recent steps in the Brazil's scientific and technological output, and most importantly, it highlighted how much progress remains to be made in order to get a little closer to the developed countries. In this regard, the main bottlenecks of our innovation system were also identified, based on information, data, and specialized literature.

The other presentations followed in the same direction, highlighting the challenges and opportunities involved in making Brazil a more innovative country. Researchers at MIT's Industrial Performance Center argued about the importance of bringing Brazil into global value chains and global knowledge-production networks. They also revealed that Brazil has great potential and could play a leadership role in the production of biopharmaceuticals. To accomplish this, Brazil would need to develop a more dynamic venture capital market, similar to what is in place in the United States and in the Boston region in particular, which is one of the major global poles of health research. According to the presenters, this would also require reducing the adoption of sets of policy instruments that block the country from gaining access to cutting-edge technologies developed in other countries, such as local content policies.

Entrepreneurs have argued that it takes more than funding and facilities to foster innovation. It also requires a stimulating and dynamic environment that allows acquired skills to flourish and thrive properly. According to them, there is great academic competence in several areas in Brazil, but excessive bureaucracy and a weak business environment make it difficult to apply the knowledge acquired at universities and turn it into new products. Brazilian entrepreneurs also took part in the debates. Among them was a Brazilian doctor with experience in rare diseases, who was the founder of a health technology company in the United States. He spoke about the health research process in Brazil and reinforced the need for increasing clinical research output in the country so that the sector could join global knowledge production networks. According to him, Brazil takes too long (one year or more) to approve clinical studies, whereas in other countries it would only take days. This delay is due to a long and bureaucratic approval process, which is subject to review by various boards. Moreover, unlike in other countries, in Brazil there are several prerequisites such as a mandatory perpetual supply of drugs to participants in certain clinical trials. Business people and health entrepreneurs have ultimately advocated that technical bodies such as the Brazilian Health Regulatory Agency (Agência Nacional de Vigilância Sanitária – Anvisa) have their leaders appointed based on technical ability rather than political pressure. This calls for adequate procedures, such as search committees, that look to reduce the level of purely political nominations to entities with strictly technical function.

Young Brazilian researchers at universities in the Boston area described their experience doing research in state-of-the-art labs. The availability of the latest equipment, research supplies, and contact with researchers of different nationalities and diverse backgrounds were frequently referenced as advantages of being in the Boston region. All of these researchers, while expressing their desire to return to Brazil and to contribute to local scientific production, also expressed concerns about their future in the country. Everyone shared the perception that the possibilities of a professional career in Brazil are very limited.

All of these discussions occurred during presentations by local researchers and visits to renowned centers for scientific research at MIT, which in turn highlighted the massive challenges and potential that lie ahead. One research team, for example, was exploring the possibility of using big data tools to reduce the costs of health systems and has developed relevant work in several countries. Laboratories such as the Media Lab, a multidisciplinary research center growing out of the MIT School of Architecture and Design, conducts extremely creative pieces of research in a vast range of fields of knowledge. Visits to the research and development (R&D) centers of local companies completed the highly dynamic and creative innovation ecosystem setting. Their existence could teach us a great deal about improving our own system and environment for innovation.

Additional discussions were held in Washington DC, with Brazilian researchers and entrepreneurs working in universities and local institutions, but this time focusing specifically on health innovation. All of the participants had substantial, long-term experience in the area, and much to contribute to the construction of a more innovative Brazil. Once again, the presenters raised the need for encouraging clinical (human) and pre-clinical (animal) trials in Brazil as a basic requirement for the country's improved performance in health research. This would stimulate, for example, a more efficient regulatory process, which could be attained in part through the participation of the relevant regulatory agency in the entire research process for a new drug, from preliminary research to its development. Being well-informed about the research would help regulators decide more quickly whether to approve a preclinical or clinical trial. The presenters noted that this shift would also require adequate infrastructure for pre-clinical studies, such as centers of toxicology.

All of the researchers who presented, without exception, emphasized the need for agility in all phases of the health research process, and for eliminating unnecessary bureaucracy. They also highlighted the need for greater internationalization of companies, of local science, and even of regulatory bodies, which should be more aligned with regulatory processes elsewhere in the world. Lastly, researchers and entrepreneurs noted that the most noticeable difference between the United States and Brazil is the former's more diversified, dynamic, and entrepreneurial academic environment.

The last phase of the study mission included a series of presentations and discussions with members of the United States government agencies in charge of science and technology (S&T) policy. In the United States, several different agencies and government organs formulate and implement S&T policies, making these policies more complex and diversified than those in Brazil. There is also strong integration between scientists and government bodies, and it is common for scientists to hold government positions relevant to S&T policies. One of the speakers was an adviser to the United States Department of State for S&T, a post traditionally appointed by the National Academy of Sciences. This is yet more evidence of the significant role of science in formulating public policies in several areas, not only in S&T public policy.

United States government interlocutors emphasized that while public investments in R&D are high in the United States, there is also a long-term trend of growing corporate participation. Increasingly, companies are investing money in technology and, to some extent, also in research that could lay the foundation for their future innovations.

Public and private investments occur through diverse means, sometimes directly to research institutions and universities and sometimes to start-up companies as venture capital or seed money. In countries with better conditions for doing S&T work, these investments produce better results.

Several of the speakers offered their perspective on what these conditions are. The first condition is human capital: there is no science without people. The second is infrastructure, including facilities and equipment, which allows a country's human capital to produce S&T. The third is the economic and business environment: there must be a flexible regulatory environment, free from excessive bureaucracy and favorable to the translation of scientific knowledge to the private sector. This same environment must ensure that laws are obeyed and that the judicial system functions efficiently. The so-called "rule of law" is vital to ensure predictability and thus expected returns on risky investments, such as investments in technology. Similarly, there must also be a system of intellectual property that provides guaranteed returns to the investor and that hinders neither the innovation process nor access to new technologies.

One final factor, also related to the innovation environment, concerns market structure. Competition is a fundamental driver of innovation. Innovation is, first and foremost, the result of companies' attempts to expand their market share, or protect themselves from potential or actual competitors. A closed economy, in which companies are protected from foreign or domestic competitors, stifles innovation. Together, these elements determine a country's capacity to produce new knowledge and technologies, as will be discussed in greater detail in subsequent chapters.

The next section in this text (chapter 1) examines Brazil's effectiveness in using and producing new knowledge and technologies, a crucial factor for the country's development.

The second chapter addresses one of the key conditions for attaining innovative success for any given country, and the basis for everything else: a quality education for all. In order to produce technology, countries must be able to train numerous talented scientists.

These scientists and researchers, however, also need adequate working conditions to produce new knowledge that may later be translated into new technologies. The first and most fundamental of these factors is infrastructure. That institutions have facilities and research equipment capable of providing stimulating working conditions is crucial to the success of technological endeavor. The third chapter addresses this topic.

In the fourth chapter, we discuss yet another factor that is critical to converting society's accumulated knowledge into new products and services, that is to say, innovations. Innovation depends on companies being compelled to create new products and, in some form, being rewarded for doing so. A competitive and stimulating economic environment is crucial to incentivizing companies to innovate. Without them, the knowledge acquired at university would not be applied to develop innovation. Thus, this chapter will discuss how our economic environment could be more conducive to innovation.

Finally, public policies and the state play a fundamental role in at least two main areas. First, throughout the world, the state is the greatest sponsor of scientific and technological entrepreneurship, for several reasons that will be discussed in the fifth chapter. Second, since public policies affect, directly or indirectly, all the other factors mentioned above, they contribute to the technological success of a country. The sixth chapter presents a brief discussion of the specifics of innovation in the health sector, as one example of this interplay a work.

This report ends by pointing out new pathways for innovation policies, based on proposals that could help Brazil to achieve technological success in the long term.

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.

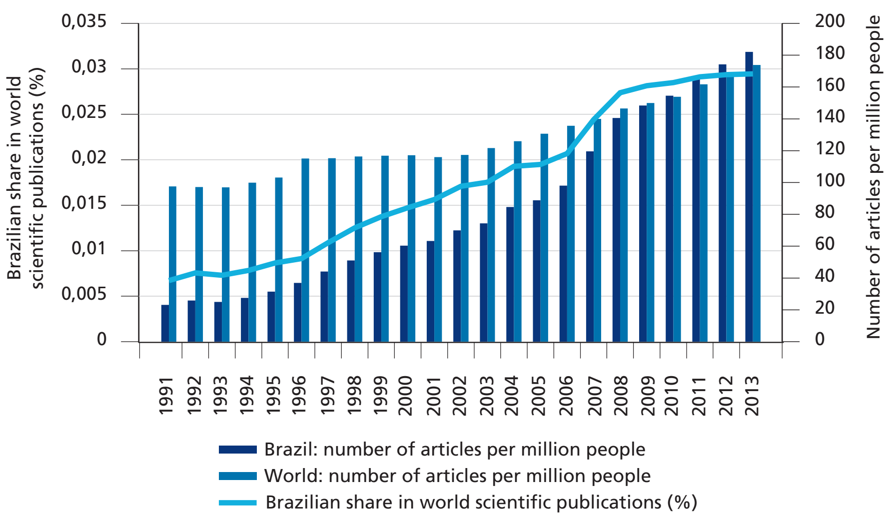
2 SCIENTIFIC OUTPUT

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.

CHART 1
Number of articles per million inhabitants in Brazil and worldwide, and Brazilian participation in global scientific output (1991-2013)



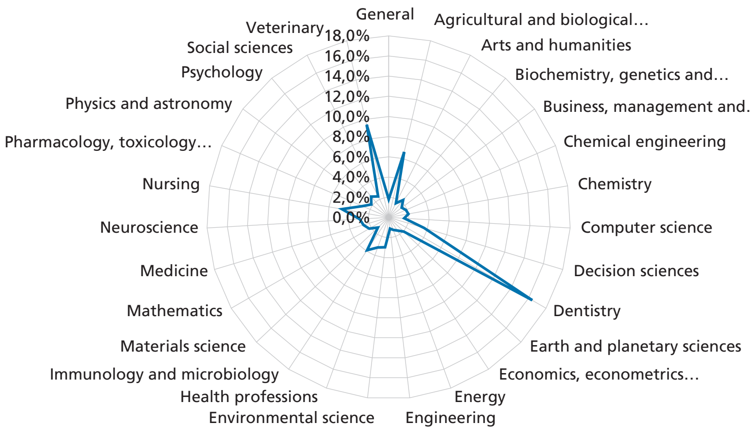
Source: Institute for Scientific Information (ISI)/Web of Science and World Development Indicators.
Elaborated by Nascimento (2016).

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)



Source: Ministry of Science, Technology and Innovation (Ministério da Ciência, Tecnologia e Inovações – MCTI). Available at: <https://antigo.mctic.gov.br/mctic/opencms/indicadores/detalhe/Producao_Cientifica/Producao_cientifica>.

No one denies that the influence of scientific research on the production of new technologies has grown substantially over the last few decades.[1] 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

1. 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,[2] 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.[3]

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.[4]

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.

4. Available at: <http://www.scimagojr.com/countryrank.php?year=2013&area=1700>.

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.[5] 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.

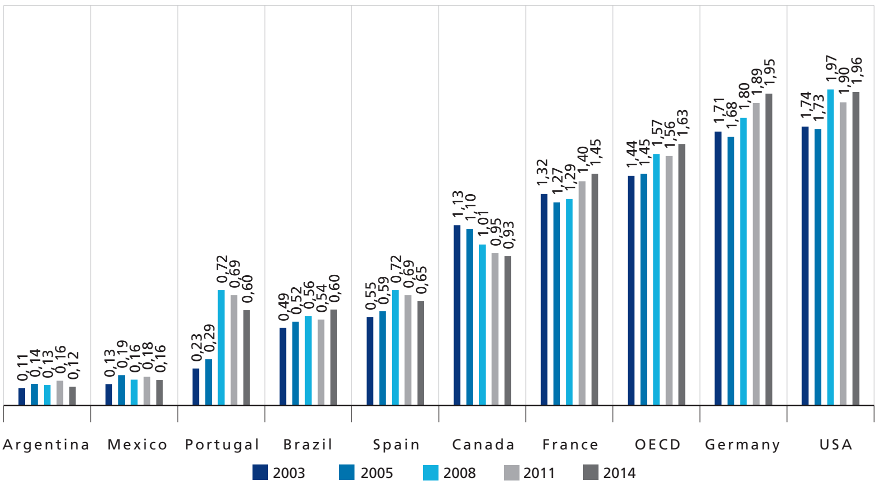
This percentage reflects the sum of investments made by the government and by companies, and changing its composition is perhaps one of the greatest challenges of the country. Although total R&D investments in Brazil are not considered low, corporate investments, which should be encouraged by public 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.[6]

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.

6. OECD data available at: <https://antigo.mctic.gov.br/mctic/opencms/indicadores/indicadores_cti.html>.

CHART 3
Business investment in R&D as a percentage of GDP in selected countries (2003, 2005, 2008, 2011, and 2014)
(In %)



Source: MCTI and OECD. Available at: <http://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB>.

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.[7] 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.[8] 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),[9] 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

7. Data available at: <https://www.gov.br/inpi/pt-br>.

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.

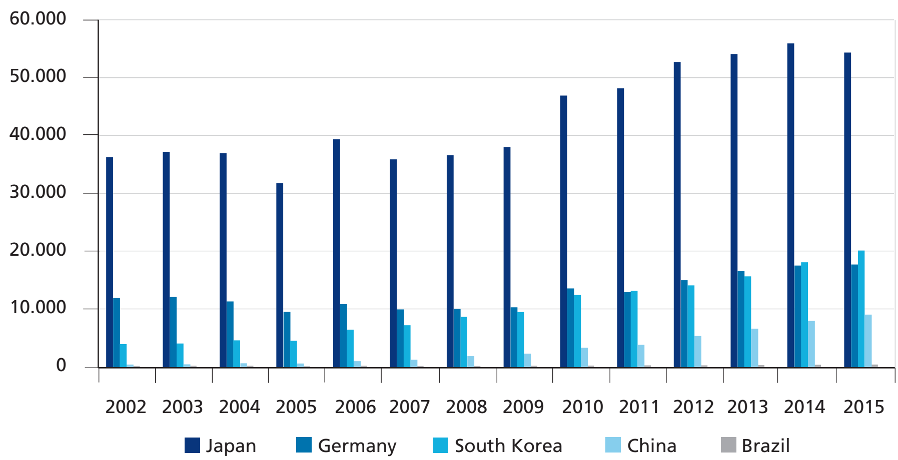
9. WIPO (2017).

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.

CHART 4
Number of patents granted per year by the USPTO (selected countries) (2002-2015)



Source: USPTO. Available at: <https://www.uspto.gov/web/offices/ac/ido/oeip/taf/cst_all.htm>.

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.

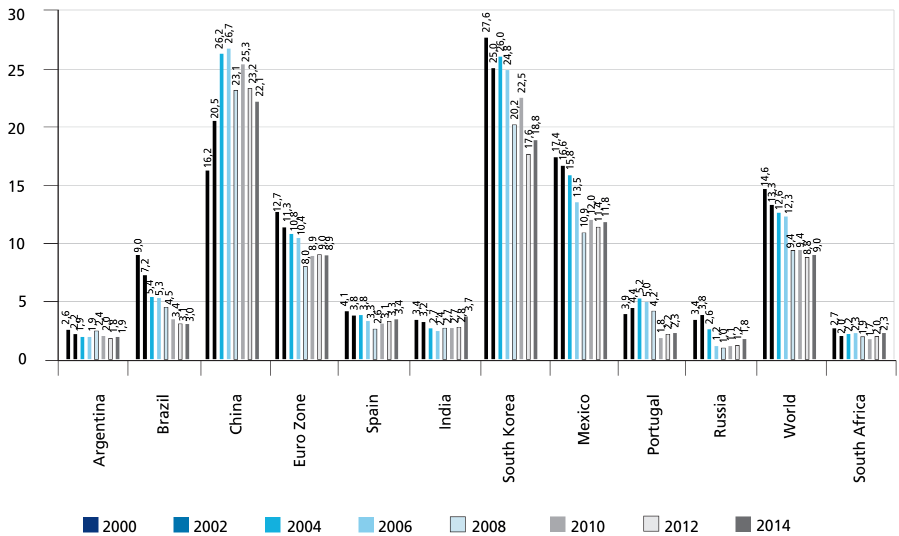
This does not mean that other sectors, such as agriculture, do not need or do not incorporate knowledge and innovation. It does mean, however, that the intensity of knowledge required by a person in charge of building an airplane is substantially higher than that of someone in charge of cultivating soybeans. 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.

CHART 5
High-technology exports in proportion to total exports of selected countries (2000-2014)
(In %)



Source: World Bank. Available at: <http://databank.worldbank.org/data>.

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.

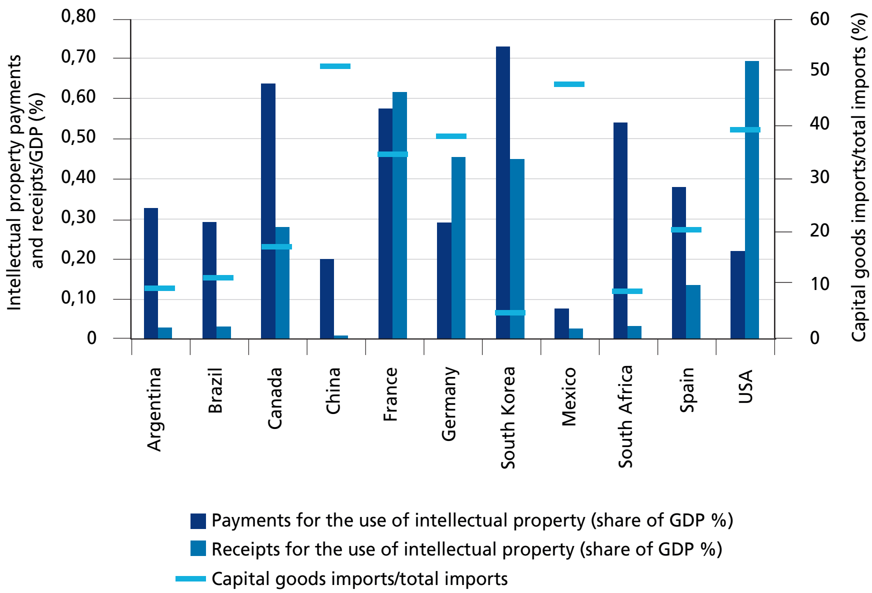
For a country far from the technological frontier, access to state-of-the-art technology is generally gained through routes such as licensing technologies, buying imported goods, paying royalties on the use of imported technologies, R&D procurement, and technical assistance. Just as it exports very little 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]

CHART 6

Payments and revenues from intellectual property rights in relation to the GDP and imports of capital goods (BK) in relation to total imports in selected countries (2015)

(In %)



Source: World Bank and World Integrated Trade Solution (WITS). Available at: <http://databank.worldbank.org/data> and <http://wits.worldbank.org/Default.aspx?lang=en>.

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

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.

CHAPTER 2

THE EDUCATION AND TRAINING OF SCIENTISTS

1 INTRODUCTION

Education is the fundamental tool for a country's scientific and technological progress. Both science and knowledge, which ultimately make society richer and more developed, are the products of people. Society invests resources in training researchers and scientists who, in turn, work to produce new technologies and new knowledge. Therefore, the basic input of technological progress is human. Obviously, scientists and researchers rely on equipment, resources, infrastructure, and a suitable and a stimulating environment, but without qualified people, none of these other conditions are sufficient. In addition, education accelerates the diffusion process of new technologies (Nelson and Phelps, 1966). A more educated society adopts knowledge and technology developed by other countries more quickly.

The goal of this section, therefore, is to discuss how education can boost a country's scientific and technological performance by training qualified people to understand and face the scientific and technological challenges of our time. The main focus will be on the aspects that most directly impact this performance, meaning that higher education (especially at the graduate level) and scientific production will be the central objects of this analysis. In addition, we will not focus on the virtues of Brazilian education, but on its challenges. Yet this section is far from being a "glass-half-empty" analysis: it is an attempt to propose solutions and pathways to transform education into an effective tool for Brazil's development.

2 ACCESS TO EDUCATION HAS GROWN, WHILE QUALITY...

Given the positive effect of education on economic growth, it is no coincidence that universal access to education has been a crucial goal of virtually all countries in recent decades, especially developing countries. One of the United Nations Millennium Development Goals was, rightfully, that all children would have access to primary education by 2015. Although universal education was not achieved worldwide, the effort produced an increase in the average elementary enrollment rate in developing countries, which rose from 83% in the early 2000s to 91% in 2015.

In Brazil, according to data from the National Household Sample Survey (Pesquisa Nacional por Amostra de Domicílios – PNAD), the average number of years of schooling for the Brazilian population increased from 6.2 years at the beginning of the 2000s to 8.7 years in 2014 (Tafner, 2017). This means that, on average, each Brazilian studies for 2.5 years longer compared to 2001. This represents a huge advance in access to education in the country, an advance that, it is worth noting, began in the 1990's.

Literacy rates have also increased. World Bank data shows that from 2000 to 2014, the percentage of literate adults in the Brazil increased from 86% to nearly 92%.[1] This is a significant rise, but still insufficient to eliminate illiteracy, as is the case in developed countries, or even to reach the level of other developing countries. In Mexico and South Africa, for example, about 94% of the adults are literate; and in Argentina, the number has already surpassed 98%.

Access to higher education has also increased. Researcher Simon Schwartzman showed that from 2001 to 2015 enrollment in higher education grew from 3 million to 8 million, an expansion mainly driven by private institutions.

However, this expansion of access to education does not seem to have reduced the gap that separates Brazil from developed countries. In Brazil, the increase in schooling does not seem to be reflected in higher levels of productivity or income relative to other countries.

This apparent lack of impact from increased levels of schooling on growth may be due to a crucial issue for many countries: quality of education. In fact, a recent study on the impact of education on economic growth showed that the quality of education is more relevant for explaining growth than the number of people with formal education or the average number of years of schooling (Barro, 2001).

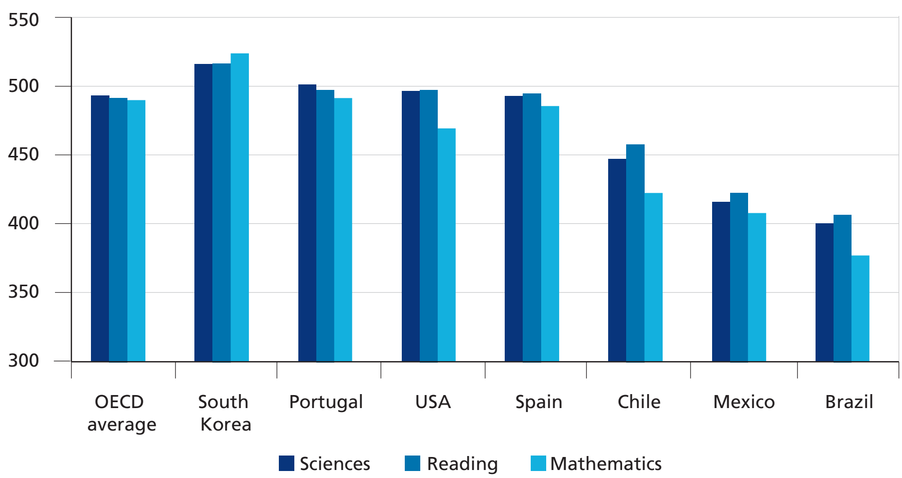
In this respect, perhaps one of Brazil's greatest challenges in education is improving the quality of primary and secondary education. The main problem is that, in recent years, quality has not improved; in fact, it has declined. For instance, the proficiency of Brazilian elementary and secondary school students in Portuguese and math is currently lower than it was in the mid-1990s. Data from the Basic Education Assessment System (Sistema Nacional de Avaliação da Educação Básica – SAEB) revealed that, in 1995, students who had just finished high school scored on average 290 in Portuguese and 285 in Math.[2] Twenty

1. More information available at: <https://data.worldbank.org/indicator/SE.ADT.LITR.ZS>.
2. Of a total of 425 in Portuguese and 475 in Math.

years later, in 2015, senior-year high school students scored lower: 267 in both disciplines.[3]

This worsening occurred against the backdrop of an already unfavorable picture. In terms of comparison between Brazil and other countries, Brazil has one of the lowest scores on the OECD's International Student Assessment Program (PISA). Although not all countries participate in the assessment, Brazil is behind many Latin American countries, and is far behind all Organisation for Economic Co-operation and Development (OECD) member countries. Although the average score in developed countries is about 600 points, in Brazil it is less than 400 points. In addition, Brazil's weakest performance by far is in math, given that only 30% of Brazilian students perform satisfactorily, according to the OECD.

CHART 1
Results of the international student assessment in science, reading, and math (2015)



Source: OECD and PISA. Available at: <http://www.oecd.org/pisa/>.

Chart 1 shows Brazil's PISA results in 2015, compared to several other countries. These numbers, and what they reflect in terms of learning, reveal a challenging reality: that our students leave elementary and secondary school retaining very little of what they read, and understanding very little about math and life sciences. Essentially, they understand very little about how the world functions. A study conducted in 2015 by the Circle of Mathematics showed that 75% of Brazilian adults do not know how to calculate a simple average, and 60% claimed that they did not like math in school.[4]

3. These numbers were introduced by Tafner (2017).
4. Available at: <http://veja.abril.com.br/educacao/adultos-brasileiros-nao-sabem-matematica-basica-diz-estudo/>.

The difficulty Brazilian students (and adults) have in quantitative disciplines, especially mathematics, helps to explain why the country produces so few engineers and scientists. And that is not all: this struggle impacts society, regardless of the student's future higher education. Increasingly, new technologies require that regular people and workers possess problem-solving and logic skills, and other abilities that depend heavily on learning science and mathematics.

The growing need for this type of skill has led many countries to proactively foster education in science, technology, engineering, and mathematics, collectively known as the STEM fields. Good quality training in these areas "should broaden students' understanding of how things work and enhance their ability to use technologies" (Bybee, 2010). Engineering in particular is a field directly related to problem solving and innovation, and thus essential for countries wishing to become more innovative.

As a result, a number of countries have adopted explicit strategies and policies to stimulate young people's interest in these fields, as well as to foster youth education. The OECD synthesized several of the principal strategies and policies adopted by member countries in relation to teaching these fields.[5] Some of them aim, for example, to increase enrollment in these fields in higher education, by offering scholarships or other financial incentives (as in Argentina, Australia and Denmark), or free classes for struggling students (as in Sweden and Germany). Other types of policies are aimed at improving the quality of instruction in elementary school by increasing the number of teaching hours (such as Germany, Ireland or Norway) and curriculum changes (Australia and the United Kingdom).

Brazil has also tried to boost, although in a limited form, instruction in these fields at the undergraduate level through the science without borders program. It is important to remember that, despite its many problems (which will be addressed later in this volume), the program's objective was to grant scholarships at foreign institutions for Brazilian students studying science, technology, engineering, and mathematics.

3 A COUNTRY WITH FEW SCIENTISTS AND ENGINEERS

Our historic problems with scientific and technological education at the basic level, combined with the low quality of teaching and the fact that Brazil has never had an explicit policy of strengthening these fields, has taken a toll. The cost has been the low number of scientists and engineers in Brazil – keep in mind that the

5. Included in the content available on the institution's website: <https://bit.ly/3xaBpwT>.

key input for producing science and technology is human capital – which makes explicit the fact that Brazilian society allocates limited resources to innovation.

It is obvious that Brazil has good scientists, who do a great deal with the infrastructure available to them. But we must recognize that the country produces few scientists and engineers, hugely limiting its scientific and technological output both directly and indirectly: directly, because there are fewer people thinking about and producing science and innovation; and indirectly, because having fewer people in these fields also means less competition and less interaction, aspects that exert a strong impact on the quality of scientific and technological output.

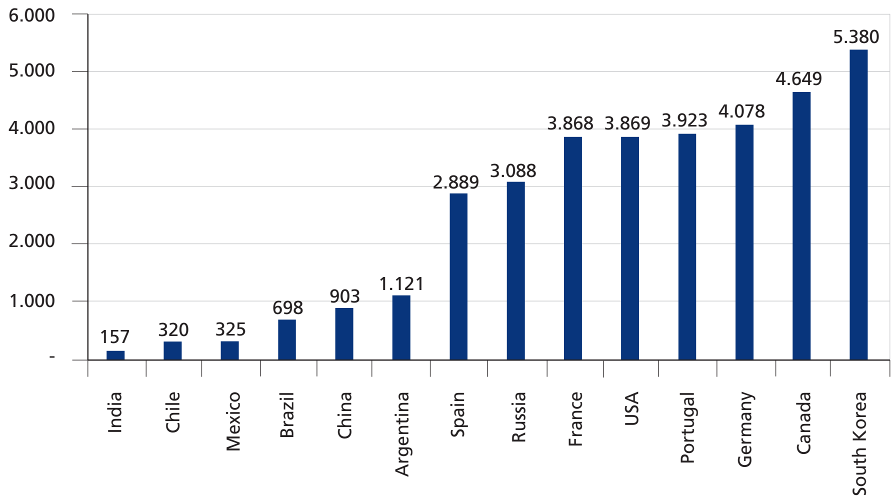
The University of São Paulo (USP) Observatory of Innovation recently confirmed that the number of trained engineers per inhabitant in Brazil is much lower than in many other countries (Salerno *et al.*, 2012). Nearly 50,000 engineers (in the many areas of engineering) graduate from Brazilian universities every year, which accounts for about 6% of the almost 900,000 annual college graduates. This corresponds to roughly 2.8 new engineers per year for every 10,000 inhabitants, which is much lower than in countries like South Korea (19 engineers per 10,000 inhabitants); Spain (10 engineers) and Mexico (8 engineers). In the United States, a country that graduates over 5 engineers for every 10,000 inhabitants, growing concerns in recent years over training people in the STEM fields have prompted new public policies aiming at improving this picture.

Just like engineers, scientists and researchers are also scarce in Brazil (chart 2). The country has about 700 scientists per million inhabitants. This proportion lags far behind that of more developed countries (where the figure can surpass 4,000 scientists per million inhabitants), and is also behind Argentina and even China, the country with the world's largest population.

The president of the Brazilian Academy of Scientists (Academia Brasileira de Ciências – ABC) noted this low number of scientists in a 2017 article. In his opinion, increasing the number of scientists would require elementary schools to awaken their students' curiosity about science and their interest in these careers. There is no doubt that these results confirm, in absolute terms, that Brazil has few engineers and scientists – but is the solution simply to train more scientists, researchers, and engineers, thereby increasing the supply of such professionals in the Brazilian economy?

This is where the question becomes a bit more complex. It is certainly necessary to improve and expand scientific and technological education; and given Brazil's poor PISA scores, this must begin in elementary schools. However, economic demand for these professionals must also exist. Otherwise, these professions will not attract more young people than they already attract today. Thus the important question is whether the labor market will be able to accommodate scientists and engineers on a larger scale than it does currently. In other words, who needs more scientists and more engineers?

CHART 2
Number of researchers per million inhabitants in select countries (2010)



Source: United Nations Educational, Scientific and Cultural Organization (Organização das Nações Unidas para a Educação, a Ciência e a Cultura – UNESCO). Available at: <http://uis.unesco.org/indicator/sti-rd-hr-res>.

Let us begin by looking at the labor market for engineers, which is much larger and more diverse than the market for scientists. Prior to the economic crisis a few years ago, there was a broad debate in the media about the country's shortage of skilled labor, especially engineers. They spoke of a labor blackout, and the industry resented being unable to find qualified engineers. Headlines such as "labor shortages will halt economy" or "struggle to find skilled labor affects Brazilian economy"[6] were common in the Brazilian press, and reflected how hard it was for the productive sectors to find skilled professionals.

In a market economy, however, a shortage tends to lead to an increase in the price of the goods and services in short supply. The same goes for professional skills. A shortage of engineers should eventually drive up the wages of these professionals, as a result of demand being higher than supply. Studies by Ipea and USP revealed, however, that this wage increase did not occur in Brazil, except in specific sectors (oil and civil construction).[7] According to the authors of these studies, the average engineer's salary is about four times higher than the average

6. Available at: <https://glo.bo/2Tq5ry0>.
7. A good summary of these studies can be found in Lins *et al.* (2014).

across the entire the employed population, and nearly twice as high as the average among employees with higher education. Nonetheless, this gap has remained relatively steady over the last few years, with a few exceptions, such as in the construction and oil sectors.

In other words, although the industry has been facing a reduction in the supply of engineers to the labor market, it has not been not enough to produce an overall wage increase for these professionals. Moreover, in the 2000s, an inverse trend was observed: the wage gap between highly-educated professionals and other workers narrowed.[8] In a society where qualifications still represent a developmental bottleneck, this reduction in the salary premium for higher education is paradoxical, since it may discourage young people from seeking more schooling.

The reduction in the wage premium could be related to several factors that require further analysis. On the one hand, it may actually be related to the expansion of access to education. In fact, according to economic literature, when access to education expands, the wage gap (which favors the most skilled) usually narrows. On the other hand, it could be due to the poor quality of formal education available. In this case, a worker may have acquired higher formal qualifications, and yet still continues to perform the same functions and receive the same salary as before.

The truth is that demand for highly skilled workers does not seem to be growing significantly across the Brazilian economy, or at least not to the point of driving a wage increase for these professionals. The reasons are related to the productive sector's performance in Brazil. In short, perhaps the low number of engineers and scientists is more influenced by the demand for skilled labor than the supply of skilled labor. The section of this report on the Brazilian economic environment (chapter 4) may shed some light on several issues affecting this demand.

The job market for scientists is much more restricted and specialized than the market for engineers. A study from the Center for Management and Strategic Studies (Centro de Gestão e Estudos Estratégicos – CGEE) analyzed where scientists with masters and doctorates from domestic universities work (CGEE, 2016).[9] The study identified, among those who received their degrees from 1996 onward, those who were formally employed in the Brazilian labor market in 2014. We should note that the individuals not in the formal market might not be unemployed. They could have started their own business, continued pursuing

8. See, for example, Davanzo and Ferro (2014).

9. Available at: <https://www.cgee.org.br/web/rhcti/mestres-e-doutores-2015>.

a PhD or postdoctoral training, or could migrated abroad, but these were not included in the survey.

One of the most interesting findings of the survey is that, among Brazilian scientists, the percentage of masters and doctorate-holders employed was lower than the employment rate for graduates in non-scientific areas.

While about 80% of those with PhDs in economics, business administration, and engineering were formally employed in 2014, only 66% of PhDs in biology and 74% of PhDs in the health, earth, and hard sciences held formal employment in Brazil. The same case applies to those with masters degrees. Except for engineering, the professionals best positioned in the formal job market held degrees in the humanities and applied social sciences. What these figures show is that the Brazilian labor market does not seem to welcome scientists to the same extent that it welcomes graduates from other fields of knowledge.

Another interesting piece of information, which characterizes the narrowness of the labor market for scientists, is that among those with doctorates who are employed in the formal market, more than 70% are employed by public (mostly federal) institutions. It is also public institutions that pay the highest salaries for these professionals. To some extent, these figures reflect what Brazilian scientists already know: that most job opportunities are at public universities (federal or state). Considering that open positions for teaching in public universities are limited, the market growth for these professionals is also limited – unless, of course, other types of institutions or industries were to create new job opportunities for scientists in Brazil, but at the moment, this does not seem to be the case.[10]

Last but not least, another key issue for understanding the low number of scientists in the country is their salary. In 2014, individuals with doctorates who were employed by the formal Brazilian market earned an average of nearly R$ 14.000 ($ 3,500), or about six times the average Brazilian salary, which was R$ 2.500 ($ 660) at the time. This gap, according to the CGEE study, has remained steady in recent years, which suggests there is not growing demand for these professionals in the country.

In short, in order to increase the number of scientists and engineers, it is not enough to just train more people in these fields. It is also necessary to create the conditions that allow these professionals to be effectively employed by society. In this sense, attempts to increase in the number of scientists in Brazil should begin with a labor market that truly values these professionals. This implies creating (or fostering the creation of) other professional positions and opportunities for scientists, beyond the traditional teaching positions available at public universities.

10. Chapter 3 will address the institutions where Brazilian scientists could work.

It also implies promoting career diversification at private and public institutions, so that they can absorb Brazilian and foreign scientists. Diversification across research institutions is also critical in this regard, but as this discussion demands more space, it will be further addressed in the following section.

4 INTERNATIONALIZATION AND DIVERSITY IN SCIENCE

In 1994, a group of researchers published a book that had great impact and influence on scholars of education and scientific production (Gibbons *et al.* 1994). The researchers argued that a new way of producing knowledge was emerging, one that was transforming the old paradigm of scientific production in distinct disciplines with little communication between them. In this new model, the relevant research questions would have a stronger applicable component, thus becoming more responsive to the demands of society as a whole. This new paradigm was also transdisciplinary and would require more diversified skills. Regardless of how correct the authors were in their analysis, the fact is that both the diversity of skills and the interaction between disciplines has indeed became widespread among the best research institutions.

Let us take the example of one of the most creative and active research labs in the world today, the MIT-Media Lab, which is responsible for a series of innovations in design and computer science, in areas such as social networks, wearable electronics, and sensors. This group brings together researchers from different backgrounds, nationalities, and professional experience: among them are engineers, designers, artists, computer scientists, physics, mathematicians, and doctors. Its diversity and multidisciplinary nature is regarded as one of the greatest strengths of this group.

In fact, diversity and interaction are decisive factors for quality scientific research. Two northwestern university professors argued in a recent issue of scientific American that validation in science takes much more than replicability, using appropriate controls, and other canons of the scientific method. It also relates to the choices made about which problems and populations to study, and the different perspectives and values that are important parts of these choices. Therefore, diversity among scientists is important to reduce bias in some of these choices, and to provide different ways of looking at the world.[11]

One of the most relevant sources of diversity is cultural, resulting from the interaction between researchers of different nationalities. The United States offers perhaps one of the clearest examples of how the immigration of researchers can help fertilize a country's scientific output. The United States welcomes the most

11. More information available at: <https://www.scientificamerican.com/article/point-of-view-affects-how-science-is-done/>.

foreign students of any country: more than 700,000 per year. To walk through United States universities is to have immediate contact with dozens of different nationalities, cultures, and ethnicities. Some are there for a short period, while others stay for a few years, and a number adopt the country as their own and continue working and doing research there.

This cultural diversity is undoubtedly one of the greatest strengths of United States science, as shown by two academics who revealed how the United States benefits from attracting these researchers (Stephan and Levin, 2001). They also concluded that the impact of immigrants on science is greater (in relation to citations and other indicators of scientific relevance) than would be expected given their participation in the country's workforce.

Analee Saxenian discusses a similar argument in her book *The New Argonauts*. The author analyzes the large influx of foreign researchers from Asian countries to Silicon Valley and explains how these researchers, once they returned home, created opportunities for both their U.S. United States colleagues and a new generation of researchers in their own country. The professional and personal networks they established while in Silicon Valley were fundamental in this respect. For the countries that were able to profit from a generation of highly qualified professionals educated in some of the best universities in the United States, the so-called "brain drain" is no longer a problem; instead, it has become a source of opportunity. It is not a coincidence that scholars of international scientific mobility no longer speak of "brain drain" or "brain gain", but rather about "brain circulation."[12]

If there was any doubt left about the benefits of international mobility on productivity and the quality of scientific output, two recent studies published in *Nature* magazine and mentioned in the October 2017 issue of *The Economist* provided new and conclusive evidence.[13] The first study, carried by researchers at Indiana University, analyzed the scientific output of more than 14 million researchers, between 2008 and 2015. Scientists who had moved to a different country in that period, nearly 4% of the total, garnered more citations than those who had not moved abroad. Remember that the number of citations is a good indicator of how influential the cited work is, which also indicates its quality. Even more interestingly, this increase in the number of citations seems to be greater for countries far from the technological frontier. United States researchers received on average 10% more citations after moving from one country to another. For researchers from Eastern Europe, however, the increase in citations surpassed 170%.

12. More information available at: <https://go.nature.com/3w7TSc1>.
13. More information available at: <https://econ.st/3jxNlEU>.

The second study quoted in *The Economist* was carried out by a researcher at Ohio State University, in partnership with a researcher at the European Commission. The two showed that this impact was not restricted to the individuals who relocated, but also had a positive effect on the host country. Their study has found that places with a larger number of scientists coming and going tend to have a higher-impact scientific production.

In this regard, Brazil has failed to take advantage of the opportunities created by the growing international mobility of scientists and researchers. A strong indicator of the internationalization of Brazilian academic institutions is the number of Brazilian students living abroad and the number of foreigners in Brazil. In 2011, Brazil sent about 28,000 students to study abroad, with or without government funding (chart 3). In that same year, the country welcomed just over 12,000 international students at its universities, most of them from Portuguese-speaking countries (particularly Angola and Guinea Bissau) and South American countries (especially Argentina and Paraguay). This is far fewer than in other developed and developing countries, and is nowhere near the more than 700,000 students welcomed by the United States or the nearly 800,000 sent abroad by China each year.

This means that only 0.2% of students at Brazilian universities are foreigners, compared to 3.9% at United States universities and 17.5% at British universities. Among the more than 100 countries ranked according to this percentage, Brazil was 98th. Brazilian students studying abroad account for only 0.4% of the total enrolled in Brazil, which also put us at the bottom of the international mobility rankings.[14]

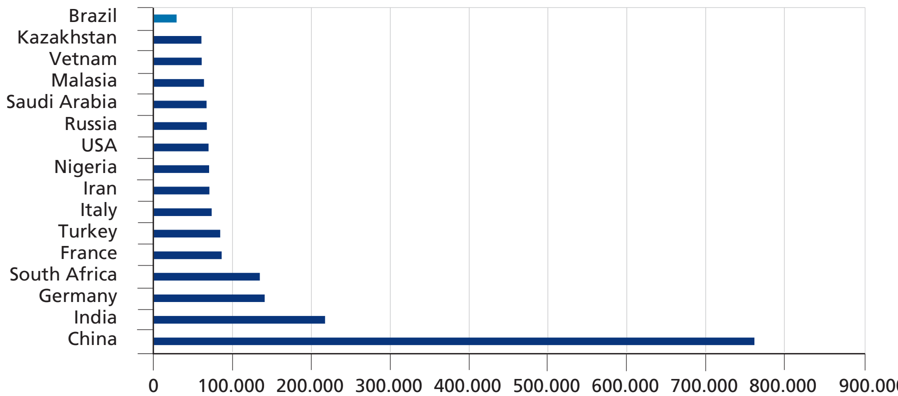
Despite the praiseworthy initiatives by some Brazilian universities and institutions to increase the number of foreigners on their staff, foreign professors and researchers are still a rarity in Brazil. The University of Campinas (Universidade Estadual de Campinas – Unicamp), for instance, is one of the best Brazilian universities both in terms of scientific and technological production (it is the university with the highest number of patents registered at Instituto Nacional da Propriedade Industrial – INPI). It is perhaps one of the few Brazilian universities with specific policies aimed at internationalization, and yet foreigners account for only 5% of its teaching staff. Among postgraduate students, foreigners account for 7% of the total. The Federal University of ABC (Universidade Federal do ABC – UFABC) in São Paulo is one of the newest universities in Brazil, and the most internationalized, according to a ranking created by Brazilian daily *Folha de S.Paulo*, which was based on the number of articles published in collaboration

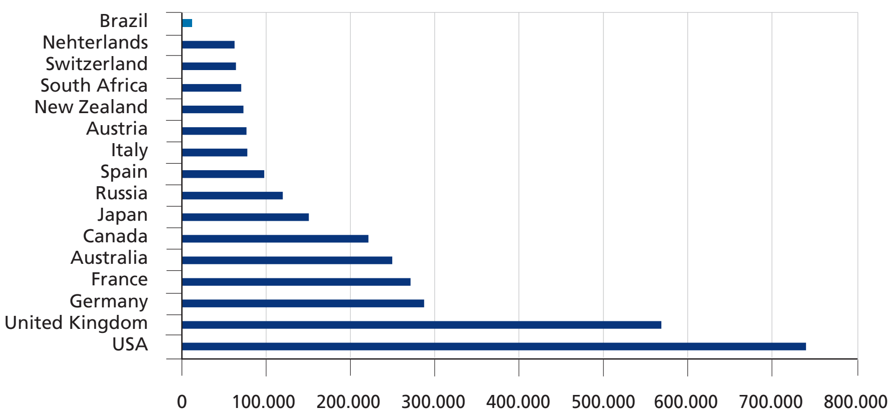
14. This data (outbound and inbound mobility ratio) is available on the World Bank website at: <https://bit.ly/3ybXuuV>.

with foreign researchers and international citations. About 10% of the teachers at UFABC are foreigners.

CHART 3

Number of students sent to study abroad and number of international students (2011)





Source: The Dutch Organization for Internationalization of Education (Nuffic). Available at: <https://bit.ly/2TjzA28>.

Are these figures reasonable compared to other institutions of excellence around the world? At the Massachusetts Institute of Technology (MIT), one of the best American universities, somewhere between 30% and 40% of professors are foreign, and 42% of graduate students are from other countries. At Cambridge University in England, foreigners make up 33% of the institution's staff, with 14% coming from countries outside the European Union. Among graduate students, more than 60% of the nearly 4,500 students are not United Kingdom residents.

Aside from these data, other studies have already demonstrated the low mobility of Brazilian scientists. A study published in 2012 at the National Bureau of Economic Research revealed that just 7% of researchers working in Brazil are foreigners – one of the lowest rates among the 16 countries analyzed (Franzoni, Scellato, and Stephan, 2012). On the other hand, only 8% of Brazilian researchers lived outside Brazil, also one of the lowest rates in that group of countries, suggesting that "brain drain" is not a serious concern.

The limited presence of foreign nationals at Brazilian universities and research institutions creates a gulf between Brazil and other knowledge-producing centers throughout the world and contributes to the small number of articles co-authored with foreign researchers. But this is not unexpected. Partnerships for the production of scientific articles, in any giving area of science, result from personal contacts and affinities. Foreign professors or researchers tend to bring with them a network of contacts and co-authors from their countries of origin, which helps to increase the international penetration of the institution where they find themselves. Researchers with little international experience typically do not know many foreign researchers with whom to collaborate.

Several recent empirical studies have shown a significant increase in international scientific cooperation in many fields over the past few years.[15] This cooperation is largely reflected in articles coauthored by researchers from different countries.

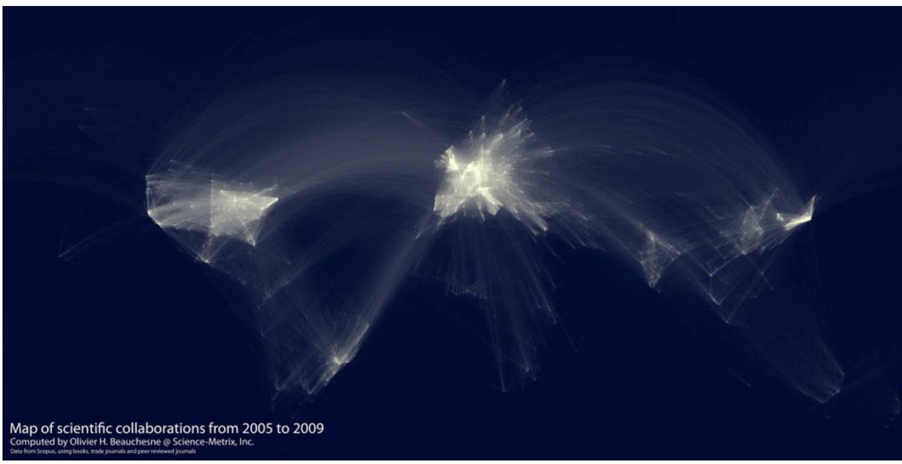
Several factors have promoted such cooperation. Advances in information and communications technology have reduced the distance between scientists, which has facilitated greater interaction regardless of physical location. Even so, scientists' increased physical mobility, which has also expanded in recent years, continues to be a decisive factor in establishing new professional and personal ties that expand their collaborative network. One last contributing factor is the growing number of transnational research infrastructures, such as the European Center for Nuclear Research (Conseil Européen pour la Recherche Nucléaire – CERN) located in Switzerland, with its giant particle accelerator, or the telescope array at the Paranal Observatory in Chile's Atacama Desert. These research facilities attract researchers from around the world, especially those from the countries that financed the venture. Considering that these are very expensive infrastructure projects for a very specific purpose (in the sense that there are few researchers able to make use of them), several countries associate themselves – or establish partnerships – with these facilities, thus ensuring that their scientists can use them for research.

Since international mobility is one of the main factors that foster collaboration, it is not surprising that the Brazilian participation in international

15. See, for example, Georghiou (1998).

knowledge networks is limited. A 2017 article in the *Pesquisa FAPESP* magazine pointed out that the percentage of articles with international co-authorship is much lower in Brazil than in countries such as Argentina, Spain and the United Kingdom, and slightly below South Korea. Yet, the percentage of collaborations in Brazil is higher than the global average. Among Brazilian institutions, the UFABC stands out for its close connections with international knowledge networks, with more than half of its publications done in collaboration with foreign researchers.[16]

FIGURE 1
Map of international scientific cooperation



Source: Cunningham, Scott and Kwakkel (2011).

In fact, figure 1 shows that although Brazilian participation in international knowledge networks is relatively small, it is certainly not irrelevant. In the figure, the density of the white lines between two regions indicates the number of scientific articles coauthored by scientists residing in both – the more lines there are, the more coauthored articles have been published, indicating greater scientific collaboration between those two regions. The whiter a particular region of the map, the greater the number of international collaborations among researchers of that region. Brazil, despite its extremely low mobility of its scientists, is still one of the most prominent countries in the Southern Hemisphere. The largest collaborative flows occur, as expected, in Europe and North America.

Several Brazilian institutions and development agencies acknowledge that the internationalization of science is an important bottleneck; therefore, they have intensified efforts to foster partnerships between Brazilian and foreign researchers.

16. See, for example, FAPESP research from May 2017: <https://goo.gl/f4NG67> and <https://goo.gl/P1wBKq>.

The São Paulo Research Foundation (Fundação de Amparo à Pesquisa do Estado de São Paulo – FAPESP), for instance, has cooperation agreements with some of the most important development agencies around the world, which has significantly broadened support for research projects that include collaboration with foreign researchers. Yet despite these types of advances, there is still a long way to go in order to place Brazil on the map of international scientific production on a more permanent and active fashion.

Another facet of this lack of diversity – one much more harmful to the quality of scientific output than low international mobility – is academic inbreeding. In biology, inbreeding is defined as reproduction between related and genetically similar individuals. Among populations where this type of reproduction is frequent, there tends to be a reduction in population variance (*i.e.*, diversity). The concept of academic inbreeding was borrowed from biology to characterize a situation in which universities usually hire their own alumni as professors and researchers.

As it does among species, academic inbreeding leads to a decrease in diversity – not genetic in this case, but intellectual – given that this type of phenomenon tends to reproduce existing knowledge, practices, and research methods in the institution. That is, inbreeding tends to create an immobile environment, which by definition is not compatible with the production of knowledge. Concerns regarding the detrimental effects of inbreeding on the academic environment are not new. In 1908, Harvard University's president at the time, Charles Eliot, wrote that it was natural, but not sensible, for a university to hire professors from among its own students. According to him, this was likely to occur because these graduates would be well known to those in charge of the selection process; nonetheless, it would not be sensible given the serious threat such a choice presented to the university (Eliot, 1908).

In fact, to date, this practice is not that uncommon in the academic setting. Although it is relatively convenient for a university to hire a familiar face, experts are almost unanimous in pointing out the negative consequences of such a practice. The most examined consequence of inbreeding is its impact on individual academic performance. According to several studies, "inbred" researchers are significantly less productivity relative to their non-inbred peers. In addition to that, the quality of their scientific output also tends to be lower. Regarding this aspect, inbred researchers tend to perform similarly to non-mobile researchers (who have not changed institutions since obtaining their first academic job), evidence that both inbreeding and lack of mobility produce very similar effects (Gorelova and Yudkevich, 2015).

However, even more relevant than the impact on individual output is the impact of inbreeding on the institution. According to the literature, inbred scholars tend to exchange ideas only with teachers from their own department and their own institution; in short, they tend to collaborate less with outside researchers. This leads to stagnation and discourages innovation within the institution. Therefore, universities with high rates of inbreeding are usually less willing to embrace changes in the environment, and less willing to change in relation to their broader social goals and challenges (Horta, Veloso, and Grediaga, 2010).

Similar results have been found in Brazil, according to a study in the 1980s that investigated academic inbreeding at Brazilian universities. The results showed a high level of citations of researchers from the same university (Velho and Krige, 1984), and thus less opportunity for intellectual renewal. This phenomenon is associated with a certain sense of institutional loyalty among the inbred researchers, which is obviously harmful to scientific production, especially when such loyalty is greater than the loyalty towards science itself. Scientists must be open to the possibility that their ideas could be proven wrong using an appropriate scientific method. Showing a stronger attachment to preconceived ideas than to methodologically-sound scientific results is not compatible with good science.

FIGURE 2
Places where Brazilian researchers work, according to the distance between their work and the place where they got their degree

Source: FAPESP Magazine.

Little seems to have changed in Brazil since the study was published in the 1980s. A recent study developed by researchers from the Federal University of Minas Gerais (Universidade Federal de Minas Gerais – UFMG), published in the *Pesquisa FAPESP* magazine showed that about 46% of the Brazilian researchers mapped by the study are working less than six miles from the institution where they graduated (figure 2).[17] This basically means that most of these researchers work at the same institution where they studied.

We can easily infer how widespread inbreeding is among Brazilian universities by performing a simple test: We only need to visit the website of any department at any of the best Brazilian universities to observe that a large number of professors graduated from that very same university.

Brazilian institutions already do not have much mobility among their professors. For reasons specific to careers in public service, professors tend to retire at the same institution where they begin their career. If we also tolerate the practice of academic inbreeding, which is a widespread practice at Brazilian universities, this scenario of immobility and its negative consequences for national scientific production will not change. In biology, "inbreeding depression" is the concept that long-term inbreeding in a population increases the risk of complete extinction of the species. This is not what we want for Brazilian science.

5 THE INTERACTION BETWEEN SCIENCE, INNOVATION, AND BUSINESS

One of the main drivers of the advancement of science is human curiosity, unconcerned with concrete results and free of any kind of tutelage or guidance. Scientific production, driven simply by this curiosity, has proven capable of opening new frontiers of knowledge, making us wiser and, in the long-run, bringing value and quality of life to humankind.

Beyond human curiosity, another key driver of scientific advancement is the search for solutions to the problems that afflict humanity and society. Living longer and healthier, working less and having more leisure time, reducing the distances that separate us from other human beings – whether through new communication channels or better means of transportation – are some of the human challenges and aspirations to which science and technology have contributed for centuries.

The path from the production of knowledge at universities to its widespread use by people necessarily passes – unless we adopt a system of production other than capitalism – through market and companies. New technologies are, after all,

17. More information available at: <http://revistapesquisa.fapesp.br/wp-content/uploads/2016/01/036-039_Mobilidade_239.pdf>.

products or services that must reach the market to be useful to people. It is not for universities (and would, in fact, be outside their expertise and purview) to take on the task of transforming knowledge into technology, and ensuring that such technologies reach their destination: the public. Even so, important segments of academia oppose what they call the "commodification" of universities, ignoring how important it is for knowledge to reach society, or the fact that there is no route aside from the economy to make this happen. Therefore, the relationship between universities and the private sector is particularly relevant to innovation and, above all, for scientific progress to create better living conditions for all. The primary input or "product" that universities deliver to society are the qualified professionals who will later work in companies producing goods, services, and new technologies. Yet the university can also offer a wealth of knowledge and research that is highly useful to most companies' innovation processes. Studies have corroborated for years the growing importance of knowledge generated in universities and research institutions for business innovation.[18] Thus, the transfer of technologies and knowledge from academia to the private sector, which occurs through various channels, is essential to amplify the impact of academia on society.

Some of these channels are informal: hiring college graduates is perhaps one of the main ways that industry can absorb knowledge from academia. In addition, publications and scientific conferences are also relevant sources of knowledge, as are, obviously, consulting activities carried out by professors and researchers. Among the formal channels are corporate-sponsored research, contracts for the assignment and use of laboratories, and the licensing of technology patented by universities. The literature shows that informal channels are likely the most common method of knowledge transfer from academia to business globally.[19] This is also the case in Brazil, as most of the national literature demonstrates.

Studies of other countries have assessed the relative importance of each of these channels. Consulting activities carried out by United States scientists and engineers appear to be the main channel for transferring knowledge to companies: 18% of the interviewed scientists and engineers engaged in this type of activity (Link, Siegel, and Bozeman, 2007). A study conducted among professors and researchers at the MIT, one of the universities in the world with the truest vocation for interaction with companies, produced similar results. At MIT, 26% of the professors and researchers interviewed identified consulting activities as the most important channel of technology transfer to companies (Agrawal and Henderson, 2002). Apparently, the consulting activities carried out by professors and researchers is often the first channel through which the productive sector

18. See, for instance, Narin, Hamilton, and Olivastro (1997).
19. Rauen and Turchi (2017) mention several studies regarding this issue.

comes into contact with the scientific and technological expertise of universities. Research sponsored by companies is, contrary to what one might expect, a much less significant channel. According to the study, the same can be said of technology patenting and licensing, which account for only 7% of all interactions with companies.

In Brazil, scholars of innovation and especially policymakers share the widespread view that the level of interaction between universities and companies is low. And indeed, until the early 2000s, this was the scenario suggested by the literature and data available (Sutz, 2000). Even recently, when analyzing this subject, eminent authors in this field, such as Suzigan and Albuquerque (2011), argued that interaction between companies and universities in Brazil is a phenomenon restricted to a few institutions and sectors. These relatively isolated "points of interaction" had historical reasons for this engagement and represent the traditionally successful sectors in Brazil, such as aeronautics, agribusiness, and oil. In these sectors, leading Brazilian institutions of scientific and technological research such as the Technological Institute of Aeronautics (Instituto Tecnológico de Aeronáutica – ITA) and the Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária – Embrapa), are the scientific points of an innovation system that also has a competitive productive sector.

However, more recently, there has been a proliferation of new indicators and analyses suggesting that the situation in Brazil has changed significantly in the last decade. One of the main indicators is based on the National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq)'s research group directory. This directory includes nearly 30,000 active research groups at Brazilian universities and research institutions in all areas of knowledge. In 2002, 8% of these groups reported having some type of relationship with companies — a number that grew to more than 13% by 2010. In engineering (which encompasses the fields most prone to some relationship with companies) and in agricultural sciences, this percentage rose to 30% and 26%, respectively.[20]

A recent survey conducted by Ipea, in partnership with CNPq, on laboratories and other types of research infrastructure in Brazil revealed an even more significant scene (De Negri and Squeff, 2016). More than 43% of the researchers responsible for university labs and research institutions in Brazil have stated that their labs provide some type of service (testing, analysis, consultancy or research) to companies. These researchers also estimated the percentage of research funds collected from companies in 2012: on average, just over 7% of the budget allocated for research in the more than 1,700 labs surveyed were collected

20. Data available on the CNPq website: <http://dgp.cnpq.br/planotabular/index.jsp>. Accessed in: Oct. 2010.

from private companies, and more than 20% came from Petrobras' resources for research funding. It is true that the sample used in the survey, whose focus was on laboratories (and not research groups) in science and technology, is composed of scientific fields that are more likely to interact with companies. Nonetheless, these are substantial numbers.

However, without comparable indicators for other countries, it is difficult to say whether this level of interaction with companies in Brazil is high or low. Brito Cruz brought new light to this debate, by calculating the percentage of research revenue at São Paulo's state universities, following a methodology similar to that adopted by United States universities. He found that at Unicamp, USP, and Universidade Estadual Paulista (Unesp), revenues from the private sector made up between 4% and 6% of the total research budget. This number is very close to the average at United States universities, but much smaller than at the leading universities in the United States.

In short, our universities do not have as much interaction with companies as those that stand out in the international arena, but recent numbers are far from suggesting that this is the main bottleneck of our innovation system, as many have argued. It is important to bear in mind that recent legislative changes have altered the framework for cooperation between universities, research institutes, and companies in Brazil. Until the enactment of the innovation law in 2004, there was no consolidated legal provision for universities and public research institutes to enter into contracts to provide research or services to private companies, nor to be remunerated for these activates and pay the researchers involved. As public institutions, universities, and research centers represent the majority of the research system in Brazil, the lack of legal clarity used to be a major obstacle to the realization of this kind of partnership. The innovation law filled this gap, and also provided regulation for professors at public universities, even tenured faculty, to carry out consulting activities, provided that these do not impede their university functions, thus opening up new possibilities.

That is, since the mid-2000s, a series of incentives have been created to promote greater interaction between universities and the productive sector. These incentives for university and public institution researchers to seek research contracts or offer consulting for companies are nowadays relatively similar to those offered worldwide. In fact, a case study comparing MIT and Unicamp (Reynolds and De Negri, 2017) suggested that incentives for professors and researchers to undertake research projects with companies are not substantially different at the two institutions. The conditions for implementing the research are, however, very different. The study identified several key internal obstacles, which hinder expansion of partnerships between companies and universities, notably the difficulty encountered in hiring researchers, the reduced number of graduate and postdoctoral researchers, bureaucratic red-tape, and the excessively centralized decision-making in Brazilian public universities. The external obstacles are associated with the economic environment, which does not fuel corporate demand for academic knowledge.

The analysis conducted so far on corporate funding for research shows the importance of one of the formal channels of knowledge transfer: research sponsored by companies. Yet there is another important formal channel: technology licensing. In this case, the university or research institute can protect a piece of technology developed in its laboratories by means of a patent. The university owns this patent, once it is granted by Brazil's INPI, and may transfer or license it to any company that might be interested.

In general, every major research university around the world, especially in developed countries, has a technology transfer office. This office is the unit, within the university or institute, responsible for applying for the institution's patents and for negotiating with companies interested in acquiring the right to use a patented technology (licensing) or acquiring the patent ownership. In Brazil, the 2004 innovation act requires every university to have this type of office, known here as a technology transfer center.[21] The law also established that the inventor (the developer of the technology) could receive part of the financial gains from patents licensed to companies. This created yet more incentives for boosting technology production within universities.

Whether it was the legal changes or a growing awareness of the importance of the university in producing technology, the fact is that there has been an increase in patent applications by Brazilian universities in the past few years. In 2000, universities accounted for just 0.38% of all patent applications, but that figure grew to 3% in 2016. For the purposes of comparison, in the United States this number was just under 2% in 2012,[22] and in Germany, it was around 2.5% (Dornbusch and Neuhäusler, 2015).

It is no coincidence that universities are at the top of the ranking of the most frequent institutional patent holders at INPI among the Brazilian population. Table 1 was taken from the INPI website and shows the ranking in 2015. According to the data, the top twenty patent owners include fifteen public universities, four companies and one private research institution. Meanwhile, no university is listed among the top fifty patent holders at the United States Patent Institute, and only one public research institution made the list at the European institute.

21. This sort of obligation is questionable, but this issue will be further discussed when we address public policies, in chapter 5.
22. More information available at: <https://www.uspto.gov/web/offices/ac/ido/oeip/taf/univ/doc/doc_info_2012.htm>.

TABLE 1
Ranking of the twenty top patent holders in Brazil (among residents) (2015)

Institution or company	Number of applications	% of total of applications by residents in the country
Whirlpool S.A.	90	1.9
Federal University of Minas Gerais	56	1.2
University of Campinas	52	1.1
Federal University of Paraná	50	1.1
Petróleo Brasileira SA - Petrobras	48	1.0
University of São Paulo	44	0.9
CPQD - Telecommunication Research and Development Center	37	0.8
University of the State of São Paulo - Júlio De Mesquita Filho	33	0.7
Vale SA	32	0.7
Federal University of Rio Grande do Sul	32	0.7
Federal University of Rio Grande do Norte	28	0.6
Federal University of Pernambuco	27	0.6
Federal University of Ceará	25	0.5
OKI Brazil Industry and Commerce of Products and Automation Technology SA	25	0.5
Federal University of Santa Maria	23	0.5
Federal University of Paraná	21	0.5
Federal University of Bahia	19	0.4
Federal University of Pará	19	0.4
Federal University of Paraíba	18	0.4
Federal University of Santa Catarina	18	0.4

Source: INPI. Available at: <http://www.inpi.gov.br>.

Unicamp, for example, besides being one of the best universities in the country, also has a long tradition of engagement with the productive sector and is one of the main patent holders at INPI, having obtained about 1,000 patents throughout its history. Yet according to the 2016 annual report issued by the university's technology transfer office, Inova, just 87 patents have been licensed for use by companies: less than 9% of the total. The other 91% represent registered knowledge – protected, but not being used by the productive sector. For comparison, in 2016, MIT filed 314 patents, and licensed 91. In other words, about 30% of MIT's filed patents are licensed to companies – much higher than the rate at its Brazilian counterpart.[23]

In reality, a patent protects a particular technology by preventing a competitor company from using that same technology for its own production.

23. This percentage assumes that the proportion between licensing and patent filing has remained relatively constant, which is likely, according to the information gathered from the institution.

Given that a university neither manufactures nor sells products or services, it is easy to imagine that owning patents but not licensing them to any company (a common occurrence in Brazil), is useless and instead of stimulating innovation, could impede it. The knowledge produced by universities will only be useful if it is transferred to and adopted by society and companies. Therefore, rather than seeking to patent their technologies, universities should be concerned with the effective transfer of these technologies to society (often through companies): this is where power to transform science lies.

Two reasons may explain why so many unused patents are filed and held by Brazilian universities. First, the university's ability to transfer internally-produced knowledge to society as a whole does not depend on the university alone. It also depends on an economic environment that fosters competition among companies and encourages them to seek innovative solutions from universities. At MIT, for example, the technologies patented by the institution are frequently licensed to startups founded by university graduates (Reynolds and De Negri, 2017). Large, mature companies seem to be less interested in these patents. Therefore, an environment that stimulates the emergence of new technology-based companies tends to be more conducive to the absorption of knowledge produced within academia.

A second reason may be the exaggerated patenting activism of Brazilian universities. Such activism may be due to mandatory existence of the offices of technology transfer, and to the limited material and human resources these offices have for screening the patents to be filed. Patent offices at world-class universities are staffed by qualified and experience professionals from various industries. The staff examines whether the patent to be filed is of market interest; if not, the university can decide not to file. In the Brazilian case, many of the patent offices do not perform this analysis. In general, it is up to the researchers – who may have no experience in the market – to decide whether the institution should patent their own scientific discovery.

Thus, the impact of science and academia on society depends on several factors. A competitive and stimulating economic environment usually inspires companies to innovate and to seek knowledge produced by universities. For this reason, it is crucial that companies be able to understand and absorb the cutting-edge science produced within the walls of these institutions.

On the other hand, universities must be open to engaging in a variety of ways with society as a whole, and aware that more effective use of the knowledge they produce requires converting it into technologies and products or services. Moreover, products are produced by companies, which are, therefore, an essential part of the diffusion process for scientific knowledge. Finally, science must be conscious of its role in society and aware of the great challenges of our times. This does not imply that science should be subservient to minor interests or lack excellence, but rather science should establish a connection with the world around it: a world in which scientists are increasingly relevant and influential.

CHAPTER 3

INFRASTRUCTURE

1 INTRODUCTION

The production of science and technology requires, in addition to scientists capable of leading research, an infrastructure that allows these professionals to work and fully develop their skills. Infrastructure in this sense includes physical facilities, equipment, instruments, and research inputs. The underutilization of scientists due to a lack of infrastructure – or even of institutions to house them – is, at the very least, a huge waste of the resources society dispensed over the decades to train these people. Moreover, the lack of adequate infrastructure is likely to compel good scientists to seek better working conditions in other countries. Therefore, research infrastructure is a key element for the scientific and technological development of a country. Limited or low-quality infrastructure has an adverse effect on scientists' work, reducing both its quality and its impact.

Different areas of knowledge demand different kinds of infrastructure and some depend more on large equipment than others. Particle accelerators – such as the one Brazil has in the National Research Center for Energy and Materials (Centro Nacional de Pesquisa em Energia e Materiais – CNPEM) in Campinas, in the state of São Paulo – are typical instruments for physics research, although they also have a wide range of potential applications in other areas, such as materials science and molecular biology, among others. Information technology research can require supercomputers, such as those available at the National Laboratory of Scientific Computation (Laboratório Nacional de Computação Científica – LNCC) in the city of Petrópolis, Rio de Janeiro. In the field of biology, in addition to proper equipment (such as high-precision microscopes), research involves inputs, reagents, and biological collections. And environmental research often needs collection, treatment, and observation stations.

The cost of equipment and facilities for scientific research can vary widely, but in general it is expensive. Moreover, as much of this cannot be found in the market, scientists have to developed and build their own instruments to perform specific tasks. For instance, the construction of the particle accelerator in Campinas has required researchers and local companies to produce numerous new technologies, and will cost nearly R$ 1.5 billion (almost $ 400 million). Building the particle collider located in Switzerland cost the European Union member countries about €5 billion (or nearly $19 billion), without factoring the ongoing costs of energy and maintenance. These high costs often lead countries to form consortiums to build large research infrastructures in partnership, as with the European Council for Nuclear Research (Organisation Européenne pour la Recherche Nucléaire – CERN).

Expensive pieces of equipment, such as those used in cutting-edge research, need ongoing maintenance and skilled staff to operated them. Since many pieces are imported, their purchase and maintenance requires much more complex logistics than, for example, the purchase of standard equipment for industrial use. Often this specialized equipment also requires special facilities in order to function properly, which has implications for construction techniques used. For example, laboratories housing sophisticated electron microscopes – such as those available at Rio de Janeiro Federal University (Universidade Federal do Rio de Janeiro – UFRJ) and CNPEM –, need the laboratory floor to be laid over blocks that are independent of the rest of the building, a sort of super shock absorber to minimize the possibility of even tiny vibrations, which can interfere with the quality of the images from these microscopes.[1] Thus, institutions that house such instruments must be prepared to operate sophisticated research facilities, and this is also an important point.

Given the essential role of research infrastructure, this section will examine possible bottlenecks, for the purpose of understanding how infrastructure can become a driving force instead of a brake on the technical ability of Brazilian scientists. Much of the Brazilian data mentioned here derives from an unprecedented effort by Ipea and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) to gather information on research infrastructure in Brazil between 2012 and 2015.[2] Prior to this survey, there was no information available on the subject, unlike in many other countries.

This data is vital, because a country's research infrastructure largely relies on public investment, sometimes substantial amounts. In some cases, a single investment project can take several years to complete. And that requires planning and prioritization, and thus information. The European Strategy Forum for Research Infrastructures (ESFRI), for example, creates a roadmap to select prospective research infrastructure projects in order to leverage European

1. More information available at: <https://www.tecmundo.com.br/ciencia/86319-ufrj-inaugura-melhor-microscopio-eletronico-brasil.htm>.
2. These results were published in De Negri e Squeff (2016).

competitiveness in the long term.[3] This also happens in Australia and Germany.[4] In the United States, the National Science Foundation (NSF) performs a biennial a survey on the country's research and engineering facilities, in order to assist the United States Congress in planning the budget for these initiatives.[5]

In addition to this type of publicly-funded installation, private sector companies have their own research and development (R&D) laboratories. However, these facilities will not be included in the discussion as they are private goods, not public ones like scientific research facilities. We will start with an overview of how Brazil's scientific and technological research infrastructure is distributed.

2 WHICH INSTITUTIONS HOUSE BRAZILIAN RESEARCH FACILITIES?

When we think of scientific research, the first place that springs to mind is the university. In fact, in Brazil, it is the universities, especially public universities, that house most of the scientific infrastructure in the country. But this is not the only viable model.

Simon Schwartzman (2013), a Brazilian researcher on education, argues that the connection between higher education and scientific research developed in the nineteenth century in the German academic system. This linkage coincided with the emergence of chemistry as both a significant industrial activity and an area of emerging scientific research. The former required training skilled labor, and the latter required training scientists. It was natural, then, to concentrate this training within the same institution. Other factors also contributed to this configuration, but as the German model became a source of inspiration, its influence spread beyond its borders. However, as Schwartzman points out, by the twentieth century, cutting-edge research no longer fit neatly within the university system in Germany, and was beginning to shift to the Kaiser Wilhelm Gesellschaft, now called the Max Planck Society.

One of the main characteristics of the German science and technology (S&T) system is its institutional diversity and decentralization. Much of the state-funded research is conducted outside universities, in institutions dedicated solely to research. Out of the more than €19 billion that the German federal government invests annually in science and technology, a little over € 3.5 billion is allocated to research at universities and university hospitals. In contrast, about € 9 billion goes to non-profit private research institutions such as the Max Planck

3. Available at: <https://bit.ly/3qF4nCq>.

4. Strategic roadmap for Australian research infrastructure and Helmholtz-Road-map for research infrastructures.

5. Available at: <https://www.nsf.gov/statistics/srvyfacilities/>.

Society.[6] Of the remainder, nearly € 2 billion goes to federal research institutions, and another € 2 billion to corporate research.

The Max Planck Society is, therefore, one of the institutional pillars of the German S&T ecosystem, which is based on a division of labor across the major research institutions. For instance, despite being independent of the government (being a private, non-profit entity), the Max Planck Society receives about € 1.8 billion from the German government, accounting for a good portion of its budget. The institution is in fact an association of 83 varied and relatively autonomous research institutes, which conduct basic research in natural science and the health and life sciences (there are also a few materials science and technology institutes). Another important institution is. Unlike Max Planck, the Fraunhofer Society is focused on innovation and applied research. For this reason, the vast majority (86%) of its budget of more than € 2 billion comes from research contracts jointly funded by private enterprises and the government. The Fraunhofer Society is composed of 69 institutions focused on different technologies in several regions of Germany and abroad. There is also the Leibniz Association, which connects 88 independent research institutions focused on social issues.

All of these research institutions conduct scientific and technological research internally, which means that they have a staff of researchers and laboratories or private research facilities. But there is also a separate institution devoted to building, operating, and managing large research infrastructures, such as particle accelerators or research vessels, among others. Called the Helmholtz Association, it operates eighteen research centers, which are all open to researchers from universities and institutions in Germany as well as from other countries.

Several other countries also have institutions devoted exclusively to research excellence. A significant part of the United States' research infrastructure is concentrated in the Federally Funded Research and Development Centers (FFRDCs), which are better known as the "national laboratories". There are more than forty of these institutions spread across the country, many connected to the Department of Energy for example, with a diverse range of laboratories and other facilities open to their own researchers and to researchers from other institutions and universities.

In the rest of the world, including in Brazil, a significant portion of public investment in S&T is earmarked for the construction and maintenance of research infrastructure and facilities. In recent years, until 2015 (after which resources for S&T in Brazil plummeted), Brazilian research infrastructure

6. Available at: <www.datenportal.bmbf.de/fig-11>.

received substantial funding from various sources, especially the Infrastructure Sectoral Fund (Fundo Setorial de Infraestrutura – CT-Infra). The Ministry of Education (Ministério da Educação – MEC)'s Coordination for Improvement of Higher Education Personnel (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Capes) program and companies such as Petrobras have provided additional resources.

Thus, it is safe to say that the Brazil's research infrastructure is relatively up-to-date. In fact, a study conducted by Ipea, Ministry of Science, Technology and Innovation (Ministério da Ciência, Tecnologia e Inovações – MCTI), and CNPq (De Negri and Squeff, 2016) revealed that most of the laboratories and research facilities in Brazil began operating in the 2000s, which could be a result of the increased investment in science, technology, and innovation from the mid-2000s to 2014 (table 1). In 2012, the authors surveyed around 2,000 researchers in charge of laboratories at universities and research institutions in Brazil. More than 70% of respondents claimed that they had received significant investments in the five years prior to the survey, and most of them mentioned substantial investments also in the previous year.

TABLE 1
Number of research facilities[1] in Brazil, according to the year of start-up

First year of operation	Number	%
Pre-1970	50	2.8
1970-1979	110	6.3
1980-1989	193	11.0
1990-1999	410	23.3
2000-2009	654	37.2
2010-2012	343	19.5
Total	**1.760**	**100.0**

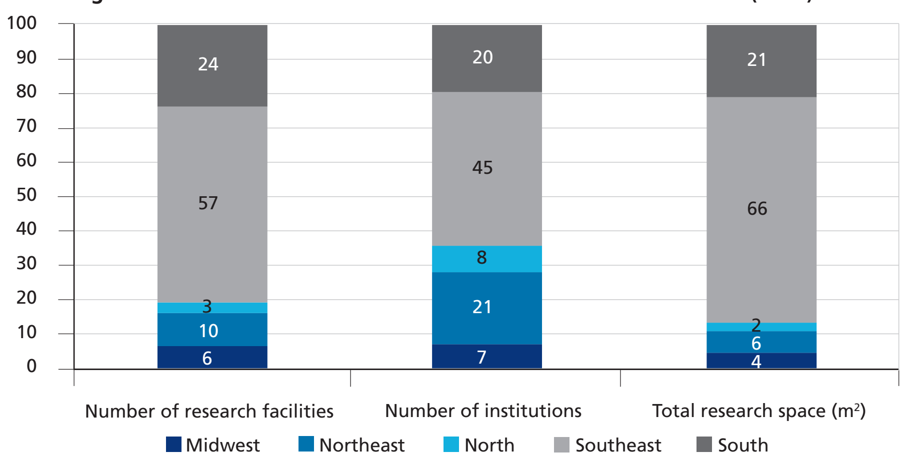
Source: De Negri and Squeff (2016).
Note: [1] The term refers to the facilities used by researchers to carry out R&D activities. This includes laboratories, high performance computer networks, observatories, telescopes, research vessels, experimental stations, and so on (De Negri and Squeff, 2016, p. 17).

Although relatively updated, almost the entirety of Brazilian research infrastructure is located within universities (unlike in many other countries). This means that these laboratories must not only train professionals for the private sector and train scientists, but also conduct cutting-edge research. Yet this wide range of activities cannot always be carried out simultaneously.

This infrastructure is also regionally concentrated, with most of the research institutions and facilities located in the Southeast and South of Brazil. The Ipea survey conducted shows that the Southeast of the country contains nearly 60% of the labs and research facilities available, and 45% of the total institutions included in the survey. The same is true for major universities and research institutions, which are predominantly located in the states of São Paulo and Rio de Janeiro.

As with research infrastructure, the number of universities and other higher education institutions in Brazil has also increased. From 2000 to 2013, the Brazilian federal government and its states created 89 new institutions of higher education, mainly research or technical universities – increasing the number of public institutes by more than 150% over fifteen years. Among the more than 2,300 higher education institutions in Brazil, 195 are what could be called research universities, required to teach, conduct research, and provide continuing education. Of these, 88 or so are private and, although this number might seem significant, they are only minimally relevant in terms of domestic scientific output. The top twenty Brazilian universities with the highest number of scientific publications are all public, according to the Simago ranking. The best-ranked private university sits at 23rd on the list.[7]

CHART 1
Regional distribution of Brazilian research facilities and institutions (2012)



Source: Ipea/CNPq/MCTI (2013) and De Negri and Squeff (2016).

Universities, especially public ones, figure prominently in the production of science in Brazil. There are only a few Brazilian institutions exclusively or primarily dedicated to research. Oswaldo Cruz Foundation (Fundação Oswaldo Cruz – Fiocruz) and Empresa Brasileira de Pesquisa Agropecuária (Embrapa) are the most well-known examples. In addition to these two, there are several institutions linked to the MCTI, such as the National Institute for Amazonian

7. Available at: <http://www.scimagoir.com/index.php>.

Research (Instituto Nacional de Pesquisas da Amazônia – INPA), the National Institute of Technology (Instituto Nacional de Tecnologia – INT) and the Institute of Pure and Applied Mathematics (Instituto de Matemática Pura e Aplicada – IMPA). The twenty or so institutions linked to the ministry, however, receive just a tiny share of its budget, and almost nothing in terms of Brazil's total investment in S&T.

One of the largest of these institutions is the CNPEM, which (like the other non-profit organizations associated with the ministry) took inspiration from the successful management structure of the United States National Laboratories. In the United States, the national labs are managed by private companies or non-profit organizations, but financed almost entirely by public funding. This model inspired Brazil's so-called *organizações sociais* (social organizations), of which CNPEM is but one example. The *organizações sociais* were created to bring greater flexibility and agility to financial management in S&T, without reducing the government's responsibility to fund research.

One of the researchers behind the establishment of CNPEM, physicist Cylon Gonçalves da Silva, wrote that "the ambition of the team that built the National Synchrotron Light Laboratory (LNLS) [at CNPEM] was to (...) introduce a new animal to the ecosystem of Brazilian S&T: a large national laboratory".[8] According to him, they no longer wanted to reproduce the university model, with individual labs and "employers, recipients of scientific equipment acquired using public funds and immediately privatized".

The goal of CNPEM's founders was to introduce to the Brazilian system a distinct model of research facility, one that occupied different niches than traditional university labs. This remains a critical point for research infrastructure in Brazil: the poor diversity of its institutions. Brazilian research facilities, located primarily in the departments of public universities across the country, are all very similar. The *organizações sociais* and the other institutions cited constitute a different model, but they are still not very significant when compared to other countries, where more diverse models of research institutions and S&T support proliferate.

Different kinds of public-private partnerships in S&T are also much more common in countries other than in Brazil. It is quite common in countries such as the United Kingdom, Germany, and the United States, among others, to see non-profit associations or companies manage research institutions. Non-profit private entities in general are much more common around the world than they are in the Brazilian S&T system. Massachusetts Institute of Technology (MIT), for

8. Available at: <http://www.abc.org.br/article.php3?id_article=3700>.

example, is a non-profit private university with an exceptional ability to produce public goods: new knowledge, technologies and skilled labor. Purely state-owned or public institutions around the world are not always so successful at producing such goods.

This is a highly relevant issue in Brazil, where the inflexibility of public sector management heavily affects research institutions. As Glauco Arbix points out

> the lack of competitiveness of Brazilian research is not due just to funding volatility, it is also strongly correlated to the constraints posed by the mechanisms available at universities, in clear contrast with the existing practices at the leading research universities – those that dominate the global knowledge-production scene and look to define themselves as true engines of economic growth.[9]

The bureaucracy that ties up procurement processes, signing contracts and agreements, and hiring within public universities is one of the key dimensions of this inflexibility. In fact, this aspect has been constantly highlighted as one of the factors that makes it difficult to execute contracts with companies, or even receive donations from companies or alumni.

A recent study uses the examples of MIT and Universidade Estadual de Campinas (Unicamp), two top universities in their countries with strong connections to the productive sector, to illustrate several differences in terms of the process for conducting research sponsored by companies (Reynolds and De Negri, 2017). Generally speaking, the study shows that incentives to collaborate with companies exist in both cases, but the internal bureaucratic processes and the economic environments surrounding the two universities are quite different. From a procedural point of view, Brazilian public universities require a myriad of internal approvals from department-level to the university's executives. In United States institutions, such as the MIT, agreements are automatically approved provided the lab is available and its use will be adequately paid for by the project. There is no peer judgment on the merits of the agreement because, according to several researchers interviewed, the institution trusts its researchers.

The inflexibility of Brazilian universities was also one reason scientist Suzana Herculano-Houzel cited for her decision to move from UFRJ to a United States university.[10] In addition to the rigidity of the career path, which does not distinguish or support the most productive researchers relative to others, the researcher also mentioned the administrative inflexibility and the difficulty in using already scarce research resources. For example, she received a cash prize from a United States institution to conduct her research, but it was administered

9. Available at: <http://glaucoarbix.org/a-usp-e-os-desafios-para-a-pesquisa-de-excelencia/>.

10. Available at: <http://www1.folha.uol.com.br/equilibrioesaude/2016/05/1767938-engessamento-me-fez-deixar-o-pais-diz-a-neurocientista-suzana-herculano.shtml>.

by UFRJ. She encountered problems in using the funding that ranged from the impossibility of hiring a researcher (a role restricted to someone who had passed a public service exam) to the time it took to buy reagents and other research inputs.

The management flexibility provided by different arrangements for research institutions is expressed in a variety of ways, including personnel management. Scientific research frequently requires a very specific set of skills for a set period of time. Temporary hiring, linked to specific research projects, as well as hiring foreign researchers is relatively difficult at government institutions and public universities in Brazil.

It is no coincidence that, among the almost 2000 research laboratories mapped by Ipea and CNPq, more than 60% of the researchers are public servants, and just 14% have employment status through the Consolidated Labor Laws (Consolidação das Leis do Trabalho – CLT). Scholarship recipients in masters and doctoral programs end up as a significant part of the "work force" in such labs, around 17% of total researchers.

This is a critical point for the competitiveness of science produced in Brazilian public universities. At these institutions, a scientist has only one type of career available: that of a professor, whose characteristics are quite similar in all universities, whether state or federal. Professors are required to teach, conduct research, contribute to the administrative affairs of the institution, and participate in what is called an *extensão universitária* (university extension), which essentially consists of providing services or lectures to the community. In Brazilian public universities, there is no career that encompasses only research or only teaching. Moreover, all professors at these universities will receive job stability after a set (and generally short) period of time.

In United States universities, for example, only a minority of professors achieve tenure, that is, job stability, and there is a wide range of teaching and research careers available to young researchers. In addition, much of the country's scientific research is conducted in institutions funded by the public sector, yet run by private, often non-profit organizations. One of the reasons behind the emergence of this kind of arrangement in the United States was the option of more flexible human resource management.

As human capital is fundamental to the proper functioning of research facilities in any given country, the ability to attract and retain highly skilled professionals is a crucial advantage for cutting-edge scientific research. Perhaps our institutions in Brazil still need more mechanisms to achieve this environment.

3 SIZE AND SPECIALIZATION

Another critical factor for productivity and for the quality of science is the size of the facilities, teams, and projects. Large research facilities, as well as large scientific projects, possess several advantages due to scale and specialization that smaller projects and labs cannot always offer. These advantages range from easy access to research inputs and specialized suppliers to the availability of high-cost equipment, through a service structure designed specifically to meet the needs of researchers. Essentially, they are similar to what, in the production of goods, economists would call economies of scale.

Economies of scale are defined as a reduction in the cost per unit of a given good (thus, an increase in efficiency) that occurs when the volume of production increases. That is, producing a larger quantity allows the use of fewer inputs than would be required for a small-scale production. Economies of scale arise from several factors, including: i) workforce specialization; ii) the ability to purchase inputs in large quantities, thereby increasing bargaining power with suppliers; and iii) the development of internal services or functions that benefit the whole organization.

Although the nature of scientific activity is quite different, there are parallel factors at work in the production of cutting-edge research. Scientific knowledge tends to become more and more specialized. Scientists have to buy inputs, reagents, and equipment. Moreover, in order to focus efficiently on their central research question, scientists may require specialized services, such as testing and assays, building or adapting a piece of equipment, detailed analysis, and so on. Thus, it is quite reasonable to assume that, as in the production of goods, there may be economies of scale in the production of knowledge capable of making it more efficient when performed in large facilities.

Yet the existence of economies of scale in scientific production remains controversial and underexplored in the literature.[11] A 2013 study tried to answer this question using data from the scientific, educational, and technological output of more than 1900 German research units in fields such as biotechnology, nanotechnology, and economics (Schubert, 2014). The study concluded that, as in the production of goods, scientific production is also subject to economies of scale. Other studies have arrived at similar results based on different information and a variety of methodologies (Dundar and Lewis, 1995; Groot, McMahon, and Volkwein, 1991; Cohn, Rhine, and Santos, 1989). Together, they reinforce the hypothesis that size does matter when it comes to the productivity and quality of science.

11. Bonaccorsi and Daraio (2005), for example, found no empirical evidence to support the existence of these economies.

This does not mean, of course, that scientific research always requires large facilities to be viable or high quality. Much of the world's scientific research is still conducted at small labs within universities. Yet there are important differences with regards to how scale affects productivity across the many scientific fields. Some fields, by their very nature, demand larger facilities than others.

Particle physics, and its most varied applications, is one of them. Particle accelerators and different light sources (such as the synchrotron light source, available in Campinas) are widely used around the world for research on energy and the characteristics of matter. These are unique, gigantic facilities with steep construction and operation costs. Therefore, it only makes sense for these facilities to be shared by many scientists from different scientific fields and institutions. Other examples of large-scale research facilities include research vessels, reactors, certain types of clean rooms, telescopes, wind tunnels, and supercomputer and bioinformatics centers.

These types of research facilities are essential for conducting many of the pioneering scientific experiments that have advanced the frontier of scientific knowledge. In this aspect, regardless of any returns to scale in research units as they become larger, one thing seems widely agreed in literature: the importance of large-scale research facilities for the development of science in many areas of knowledge.

This so-called "big science" gained momentum after World War II, in the wake of the scientific breakthroughs that led to the development of the atomic bomb, and which demanded massive infrastructure and research teams. A number of research institutions and national labs that today form the core of the United States science and technology ecosystem came into existence at the height of the Cold War. These publicly-funded institutions house nuclear reactors, particle accelerators, light sources, and other large-scale research equipment. It was in one of these labs, at Los Alamos, that the atomic bomb was developed. By the late 1960s, the United States had more than seventy such institutions, almost all built after the end of World War II, which required substantial long-term public investment.

The literature highlights several positive effects of these large-scale infrastructures, not only in scientific terms, but also in terms of technological and economic development. Certain scientific discoveries and experiments are impossible without particle accelerators, light sources, reactors, or other large piece of equipment. In addition to contributing to the creation of new knowledge, these facilities have also contributed to improvements in the efficiency of scientific research by establishing quality standards for their use, which in turn have become benchmarks for other researchers and institutions. In general, this type of infrastructure is also multidisciplinary, because it exists to solve complex questions that rely on a variety of scientific knowledge and points of view. Moreover, these installations are often a central hub for global research networks, enabling a wide exchange of knowledge and information among scientists from various fields. In general, large research facilities welcome researchers from various institutions, and for this reason, they are considered "multi-user". This means that any researcher, after passing a transparent, peer-reviewed selection process, may set up a research project using the facility's infrastructure. For all these reasons, these institutions and their researchers are often responsible for much of the state-of-the-art science produced globally.[12]

Another positive effect highlighted in the literature is associated with the development of human capital, as many young scientists use this type of facility to produce their dissertations. The economic impact is also significant. The construction of this type of infrastructure requires the development of specific equipment and construction techniques, which, in turn, demands the engagement of local industries and manufacturers. In addition, many such research facilities are not for exclusive use of academic researchers. Companies and their researchers often rely on these facilities to conduct part of their research or to develop new products using equipment that would be impractical or cost-prohibitive for the company purchase.

One example is the nanotechnology research center at the United States National Institute for Standards and Technology (NIST).[13] The institution, which is akin to Brazil's National Institute of Metrology, Quality, and Technology (Instituto Nacional de Metrologia, Qualidade e Tecnologia – Inmetro), built the nanotechnology center in 2007 to provide industry, academia, NIST, and other government agencies with methods, tools and technologies for a nanometric scale. The center features a research lab and a factory, where more than a hundred employees work, including federal government employees (NIST is a public institution), temporary researchers, and graduate students.

Therefore, it is no coincidence that in recent years, several countries have devoted increasing attention to the construction of large research infrastructures. In the last five to ten years, there has been an increase in the number of countries that have developed roadmaps, in partnership with the scientific community, to define what research infrastructure is needed, estimate costs, and decide which should be prioritized for a long-term scientific development strategy.

12. Many of these arguments are detailed in a literature review carried out by the group called Technopolis for the Ministry of Education and Science and available at: <http://www.technopolis-group.com/report/role-added-value-large-scale-research-facilities/>.

13. Available at: <https://www.nist.gov/cnst>.

The ESFRI, for example, is responsible for preparing these roadmaps for the European Union. The objective is to select construction or expansion projects for research facilities capable of advancing European competitiveness in the long run. Table 2 shows some of the research facilities funded by the European Community from 2007 to 2013, under the bloc's seventh research and development action plan.[14]

Not all research infrastructure is as large as nuclear reactors or particle accelerators, but even smaller facilities abroad offer contrasting examples to most of the research infrastructure available in Brazil. Investments may vary widely, but most of the facilities selected in table 2, which are reflective of the many unselected facilities, cost more than € 50 million. Most also have an extensive number of contracted researchers.

TABLE 2
Some of the research facilities supported by the European Union in recent years: location, initial investment, annual operating costs, and number of researchers from each of them

Name	Country	Number of permanent researchers	Investment	Annual operating costs
Centre d'Elaboration des Matériaux et d'Etudes Structurales (CEMES)	France	50 to 100	50-250 M€	0.25 to 1 M€
Forschungszentrum Rossendorf	Germany	101-200	250 - 500 M €	> 10 M €
Research Platform on Nanoelectronic Systems	Germany	1-10	20 M € - 50 M €	0.25 M € - 1 M €
Central Laser Facility (CLF)	United Kingdom	51-100	50 M € - € 250 M €	1 M € - € 10 M
Robotics Research Platform	Belgium	1-10	< 20 M €	0.25 M € - 1 M €
Solar Platform of Almeria	Spain	11-50	50 M € - 250 M €	1 M € - 10 M €
European Bioinformatics Institute (EBI) European Molecular Biology Laboratory (EMBL)	United Kingdom	201-500	50 M€ - € 250 M	> 10 M €
Center for Biomolecular Magnetic Resonance (BMRZ)	Germany	11-50	50 M€ - 250 M€	1 M€ - 10 M€

Source: De Negri and Squeff (2016).

For its part, Brazil has refrained from long-term infrastructure planning, and from financing large-scale projects. Sirius, a new Syncroton light source being built in Campinas, is an exception as one of the few large-scale investment projects for research infrastructure in Brazil in recent years. Other projects, such as the Brazilian multipurpose reactor or the satellite launch vehicle (that never took off), seem to be permanently under construction. The multipurpose reactor, which would produce radioactive isotopes used mostly for medical equipment and radiopharmaceuticals, has been in the works since 2007. In 2009, the

14. This program is known as Framework Program, or FP7. It has been replaced recently by another research-oriented program, called the Horizon 2020, which also has investment goals set for large research facilities.

newspaper *Folha de S.Paulo* published an article on the project, whose estimated cost at the time was $ 500 million.[15]

There are no mechanisms for consultation or dialogue with the scientific community to determine a long-term plan for Brazil's scientific infrastructure, nor even studies related to this issue. In terms of funding, the main instrument would be one of the sectoral funds aimed at expanding the country's research infrastructure, called CT-Infra. In the absence of planning, prioritization, and sufficient funds, however, CT-Infra's resources are simply distributed among Brazilian universities on a regular basis. The universities, in turn, distribute these resources among their departments, either for maintaining or building small labs. As a result, Brazil continues reproducing the type of research infrastructure already in place: small research laboratories spread across a number of Brazilian universities.

A survey conducted by Ipea, CNPq and MCTI provides evidence of the modest scale of our research facilities in Brazil. The survey asked managers of research units and laboratories to estimate the total value of the equipment available at their research facility as well as the value of the entire installation (including the value of the buildings). More than 40% of lab coordinators reported that the sum of their equipment was less than R$ 250,000 (about $ 70,000). According to the results, only eighty-eight installations – just 5% of the sample – had equipment assets of more than R$ 5 million ($ 1.35 million). The same trend holds true for the total value of the facilities. About 60% of the coordinators claimed that the total value of their research facility, including buildings and equipment, was less than R$ 500,000 ($ 185,000).

Although we know it is difficult to estimate these values precisely, and recognize that variations are likely due to different understandings of the concepts addressed (costs, revenues and infrastructure value), all these indicators point in the same direction: the modest size of most of our research facilities. Just over twenty facility managers among the 1,760 surveyed reported that the total value of their physical facilities and equipment exceeded R$20 million ($ 5.4 million). The small scale of Brazilian research facilities is also visible in the items related to annual costs and revenues, which rarely exceed R$ 1-2 million per year. The number of researchers on the premises also points out in the same direction: about 8,000 researchers work at the institutions mapped in the survey (for comparison, more than 10,000 people work at Los Alamos lab alone), which comes to an average of four researchers per installation. Despite several important absences in the survey, it reflects a very reliable picture of Brazilian research infrastructure, confirming its modest scale.

15. Available at: <http://www1.folha.uol.com.br/fsp/ciencia/fe3005200901.htm>.

This does not mean, however, that there are no major research institutions in Brazil with characteristics similar to those of large research facilities in other countries: there are a few. The largest Brazilian research institutions are shown in table 3.

The Embrapa, associated with the Ministry of Agriculture, is undoubtedly one of the most important institutions of the Brazilian innovation system. Embrapa is a public company created in 1973 under the administration of the Ministry of Agriculture, aimed at developing applied science and technology for the Brazilian agricultural sector. Today, it has more than 9,000 employees and nearly 2,400 researchers working in more than sixty units across the country.

The Fiocruz is a public research institution associated with the Ministry of Health, and is responsible for a number of activities such as R&D, vaccine and drugs manufacturing, education and training, hospital care, and products and services quality control. The institution was created in 1900, and today has over 11,000 employees and health professionals. However, most of its employees and of its budget are not committed to performing research activities, but are rather in charge of the production of medicines and vaccines for the Brazilian health system. Its R&D activities are just an ancillary responsibility of the institution.

TABLE 3
Total budget (not just for research) of the largest Brazilian research institutions (2014)

Research institute	Budget (BRL thousand)
Fiocruz – includes manufacturing drugs and vaccines[1]	4.265.978
Embrapa	2,852,532
Butantan Institute[1]	1,090,131
Institute of Technological Research (Instituto de Pesquisas Tecnológicas – IPT)[2]	168,837
IMPA	108,771
National Institute of Space Research (Instituto Nacional de Pesquisas Espaciais – INPE)	108,409
CNPEM[3]	76,097

Source: Transparency Portal (available at: <www.transparecia.gov.br>) and MCTI. Accessed in: Sept. 2016.
Notes: [1] Includes the budget for vaccines and drugs manufacturing and for education, plus the research budget.
[2] Includes the basic budget of the State of São Paulo's (about 35% of the total) and revenue from technological services (65%).
[3] Does not include the contingency budget for building the construction of the new syncroton light ring.

The Butantan Institute, created in 1901, is connected to the state of São Paulo. Today, the Institute is the main Brazilian producer of immunobiologicals, and is responsible for a large fraction of the national production of vaccines and hyperimmune serums used by the Ministry of Health. In addition to producing immunobiologicals, Butantan also maintains zoological collections and conducts basic and applied research on venomous animals, pathogens, and immunobiologicals production and control. The institute is currently involved in research and development of a vaccine against the dengue and Zika viruses. Finally, it also offers graduate courses in its fields of expertise.

The CNPEM is a nonprofit social organization that receives public funding, but has a more flexible administrative structure than a purely public institution. CNPEM is likely one of the most efficient research institutions in Brazil and perhaps the only one with the characteristics of a large research facility like the United States national labs or similar institutions across the world. It is effectively a multi-user institution, which welcomes researchers from other institutions and has become a global reference for research using synchrotron light. Connected to the MCTI, it employs seventy-five researchers as staff. Almost 2,000 researchers used CNPEM's facilities in 2014.

CHAPTER 4

ECONOMIC ENVIRONMENT

1 INTRODUCTION

Thus far, among the critical factors behind innovative performance, we have examined those related to the supply of knowledge and new technologies, such as education and human resources training for research, scientists' performance, as well as adequate facilities for the production of science. Changes and improvements to any of these factors may increase knowledge supply to the economy, a crucial factor for innovation.

However, simply producing knowledge is not enough to become a more innovative and competitive country: it is critical, but insufficient. In addition to knowledge production, this knowledge must be transformed into new products and production processes – in other words, into innovation. Companies are responsible for this transformation, not universities and research institutions or scientists. In order for innovation to occur, industries must feel the need to innovate, to invest in new ideas and in the development of new products and processes; and finally, they must be able to introduce these new products and processes into the market.

Since companies cannot be forced to innovate, it is essential to create an economic environment that stimulates the innovation process. This is the only way to complete the cycle of innovation and technology adoption in the Brazilian economy.

2 COMPETITION, OPENNESS, AND INNOVATION

Why do companies feel the need to innovate? What motivates them to seek new tools, knowledge, and technologies to improve their products or production processes? A company innovates to gain new consumers, or avoid losing them to other companies in the market, or even to sell their products with a higher profit margin, without having to share its customer base with other companies. In other words, it is competition, real or potential, that encourages innovation. If a company is able to sustain high profit margins and a loyal consumer base without promoting improvements in its products, it is reasonable to assume that it will do just that. After all, investing in new products or improving existing ones takes effort and can be costly and risky.

The smartphones war waged every year between Apple and Samsung is a good example to illustrate how competition can stimulate innovation. These two companies control more than 60% of the world's smartphone market and every year they host a big event to announce their product releases and win new customers – either through cheaper devices or from their competitors. In 2017, for example, the two companies launched new high-end models with similar features at the same time – both claiming to be standard-bearers for the future of technology in the sector.[1] One wrong step in this technological war can have considerable impact, as was the case with the Galaxy Note 7's battery explosions, which strongly affected Samsung's profitability in that market segment.[2]

Thus, innovation is one of the key competitive tools for companies. The development of new production processes helps reduce a company's production costs, which can lead to more customers or to a bigger profit margin. Product innovation, in turn, allows the company to charge more for its product without losing (and sometimes even increasing) its customer base.

Either one of these channels gives a company more market power and profits than its competitors. This higher profit is the so-called "monopoly profit" that, in simple terms, reflects a larger profit than what the company would have if it were operating in a fully competitive market, in which other companies could offer the same good. When a company creates a feature product, for example, it is akin to having a temporary monopoly over that particular product. This monopoly and the extraordinary profit last until another company realizes the opportunity and is able to imitate the former.

This type of temporary monopoly is exactly what Apple sought, for example, in making a phone with the then-exclusive feature of facial recognition. The higher price that the company can charge for this type of innovation, or technology embedded in its device, creates the monopoly profit. In essence, even as competition drives innovation, companies also use innovation as a mechanism specifically to reduce the level of competition.

Joseph Schumpeter was the first economist to write about and to analyze the process of innovation in capitalist economies in a more comprehensive and systematized way. His work influenced much of the subsequent literature on the subject. It was his finding that what drives an enterprise to innovate is this fight for monopoly profit. In 1942, he observed that the sectors and products

1. Available at: <https://econ.st/2UY9lyB>.
2. Available at: <https://bit.ly/3AjjyG8>.

where technological progress was most evident were those involving the large conglomerates, and not those with companies operating in an environment of free competition.[3] The reason was that the size of the larger enterprises enabled them to absorb the costs and risks associated with the research and development activities that innovation requires. In addition, the larger size could also generate economies of scale by concentrating research in large research and development (R&D) laboratories.

Just like Schumpeter, many economists have realized that the positive correlation between increased competition, usually measured by lower market concentration, and more innovation is not always the case. Markets featuring a large number of producers – thus, with less concentration and more competition – are not always more innovative or higher quality markets. In some cases, smaller companies in markets with very fierce competition have fewer incentives and fewer opportunities for bearing the risks and costs associated with innovation. In many cases, in these markets, companies adopt lower prices and lesser quality – not innovation – as a competitive tool.

A good illustrative example was the 2013 horsemeat scandal in Europe. The scandal began when, in January 2013, horse DNA was discovered in hamburgers sold in Ireland and England. Further investigations revealed a number of hamburger brands in several European countries contained types of meats other than the beef indicated on the packaging. This is an example of a very competitive market with numerous producers of the same product, where price is a critical factor for success. What happened in this case was the opposite of innovation: enterprises reduced their prices by lowering the quality of the product in an attempt to claim a larger share of the market. Therefore, it is not a coincidence that the empirical literature has found diverse and rather conflicting evidence regarding the effect of competition on innovation. Some studies found positive results while others found a negative correlation between these variables.

Part of this difficulty stems from the way economists measure competition: through the participation of enterprises in the sales of a given product, which tends to be smaller the greater the number of competitors in a particular market. However, concentrated markets do not always mean a lack of competition. The Apple and Samsung case is proof of that: a very concentrated market in which technological competition is extremely fierce.

Recent studies have reached more concrete explanations of how competition affects innovation. Such studies have detected that the correlation between innovation and competition takes the form of an inverted U-curve (Eicher and

3. See Schumpeter (1943).

Kim, 1998; or Aghion *et al.*, 2005). This means that highly competitive markets, where there is a large number of small businesses and goods tend to be more homogeneous (such as hamburgers), are often less innovative. This happens because companies are smaller and exposed to huge competitive pressure, and usually opt to reduce costs and prices rather than to increase quality and to innovate.

In markets slightly more concentrated, in which companies are larger and products differentiated, there is a greater tendency toward innovation. Competition among companies in these markets is likely to focus on product differentiation and quality. However, if market concentration sharply increase and the level of competition for established companies begins to decline excessively, the incentives to innovate vanish. The opposite of this situation is monopoly; that is, in the absence of competition, a company has no reason to bear the costs or risks of innovation.

In short, with the exception of very fragmented markets, competition is likely to make enterprises or economies more innovative. Therefore, the next question is whether competition in Brazil has been a conducive factor or if its lack has been an obstacle to innovation?

One of the main channels through which a country's companies faced competition is international trade. Exposure to competition is one of the drivers for exporting companies to be more innovative and more productive than non-exporters.[4] This exposure to international markets can result from domestic competition from imported products, as well as from selling to foreign markets.

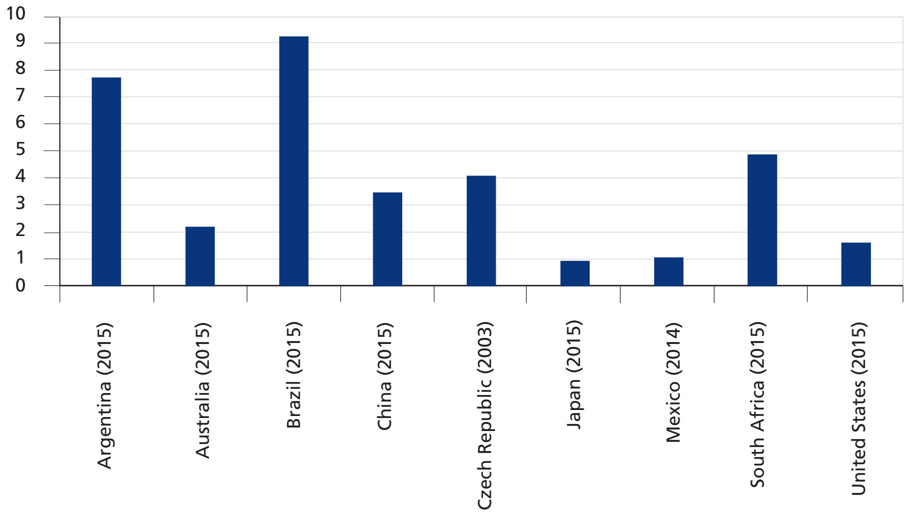
Brazil's domestic market is very protected against imports, and therefore, firms are less exposed to international competitors who are more productive and of better quality. In fact, one of the key indicators of this protection is the average import tariffs that Brazil imposes, which are quite steep compared to other countries, as seen in chart 1.

If we look at another reference point of trade liberalization, instead of import tariffs, such as the value of trade flows in relation to the gross domestic product (GDP), the result is no different. In Brazil, trade flows account for nearly 25% of GDP. That is not much, even for a continental country like ours. Compared with other densely populated countries or territories, this value is very small.[5] As is the case with import tariffs, the country most similar to Brazil regarding exposure to international trade is Argentina.

4. There is ample empirical evidence in Brazil and in the world that corroborates this relationship.

5. This is not a new finding. Available at: <https://exame.abril.com.br/economia/as-10-economias-mais-fechadas-do-mundo-o-brasil-lidera/>. For a deeper analysis, see Canuto, Fleischhaker, and Schellekens (2015).

CHART 1
Import tariffs effectively applied to industrial products in selected countries: weighted mean by the imports value
(In %)



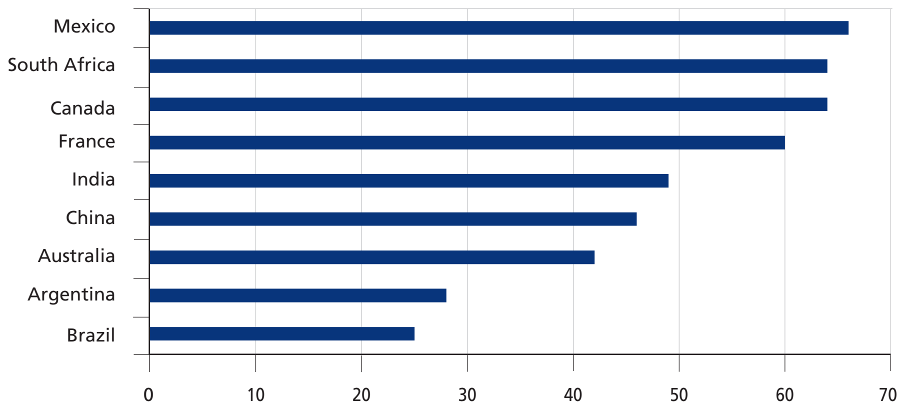
Source: World Integrated Trade Solution (WITS). Available at: <https://wits.worldbank.org/>.

One of the consequences of this lack of openness to foreign trade is that Brazilian companies have less need to seek efficiency and productivity gains, since a tariff barrier protects them from competition. The same goes for innovation. It is no coincidence that inefficient companies can survive in the Brazilian economy, and that there is a huge distribution in productivity indicators between them.

In addition to the limited exposure to competition against foreign companies, the high degree of protectionism also reduces the chances that Brazilian companies will become more competitive through using imported inputs and equipment, of lower price or better quality. Economists like Canuto and others have shown how unusual Brazil is in this regard (Canuto, Fleischhaker, and Schellekens, 2015). They examined the extent to which products exported by Brazil include imported inputs as part of their production, an indication of integration into global value chains. Compared to other countries, Brazilian exports contain very little imported inputs, which means that the country is not effectively integrated into global production.

Access to the international market of imported inputs and equipment also means having access to state-of-the-art technology produced abroad. Many of the new technologies used in industrial production are embedded in inputs or in more modern and efficient machinery and equipment. As previously mentioned, one strategy to absorb these technologies is to buy imported machinery and equipment. Now, how can a country produce new technology if it cannot even manage to use global state-of-the-art technology?

CHART 2
Trade flows (imports + exports) in relation to GDP in selected countries (2015)
(In %)

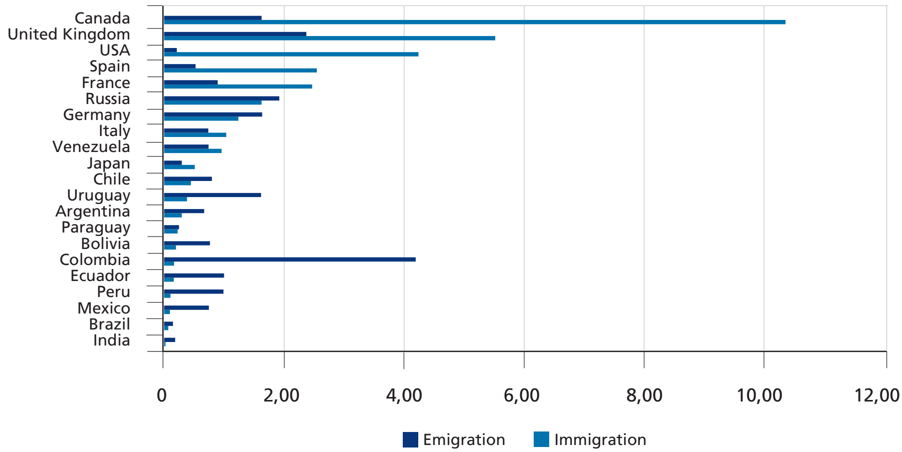


Source: World Bank. Available at: <http://databank.worldbank.org/data>.

It is likely that both the low level of integration into global value chains and the closed economy itself result from an obsolete belief that the greater the selection of goods produced domestically, the greater the country's competitiveness. From this perspective, it would be necessary to manufacture all the parts (or a large part) of a given product: from basic inputs up to the final product. The idea of developing complete domestic supply chains for every single economic sector instead of going global is obviously impractical given the current global economic scenario. In thinking this, Brazil has protected its companies from competition at the same time it has impeded them from being competitive. While supposedly protecting the Brazilian industry, we are making it obsolete.

Historically, perhaps, the policy reserving the computer market for Brazilian companies has been the greatest example of this misconception, which still lingers in the country. For decades, Brazil has been left out of the world's technological trends in microelectronics and, even worse, we have prevented companies in other sectors from benefiting from the positive impacts of these technologies on their productivity.

CHART 3
Migration of workers with higher education as a percentage of the total population in selected countries (2011)



Source: Organisation for Economic Co-operation and Development (OECD).

Our insulated culture is not much different when we analyze, rather than trade flows, the flow of people. From the point of view of innovation, the migration of highly qualified professionals is particularly important. Although concerns remain in Brazil regarding brain drain,[6] aggravated by science and technology (S&T) budget cuts (which have intensified since 2016), the migration of qualified Brazilians abroad is not as significant compared to other countries.[7] Between 2010 and 2011, roughly 295,000 Brazilians with higher education were living and working in other countries, or approximately 0.15% of the population (chart 3). In relation to select countries, including several Latin American and European countries, this percentage is only higher than that of India, with its 1.35 billion inhabitants.

The entry of skilled people to the country is even smaller than the departures. From 2010 to 2011, about 135,000 people with higher education came to Brazil, accounting only for 0.07% of the Brazilian population, a percentage much lower than in several other developing countries and significantly smaller than in developed countries. This issue was addressed in greater depth during the discussion of the internationalization of Brazilian science. The exchange of experiences with other cultures and the absorption of foreign professionals' skills is important not only for scientific production, but also for the production of innovation in companies.

6. Available at: <https://glo.bo/3wbTbhK>.
7. According to international migration data from the OECD, available at: <http://www.oecd.org/els/mig/dioc.htm>.

3 COST OF CAPITAL

Brazil has been, for more than two decades, the country with one of the highest real interest rates in the world. Obviously, this affects companies' investment capacity, concerning both the funding cost and the opportunity cost, which reflects the return forgone on alternative investments. Put simply, if the expected return on a certain investment is lower than the interest rate charged by the banks or lower than the return on some alternative investment, that investment is not compensatory. Innovation is even more vulnerable to high interest rates than investment in machinery, equipment, and construction because it is a riskier investment and risks reduce expected returns.

It is not the focus of this paper to discuss the reasons behind high interest rates in Brazil. The literature lists reasons ranging from the size and trajectory of public debt – in relation to GDP and the tax burden – to issues related to regulation and competition in the banking sector, to the hyperinflationary history of the country. It is likely that all of these factors play a role. What is interesting to us, for the purpose of this report, is that high interest rates, combined with a minimally functional financial market, negatively affect the economy's investment capacity and, even more intensely, investment in innovation.

The impact on investment in innovation is greater for many reasons, given the existence of financing constraints even under normal interest rate conditions. In fact, the literature points out the existing gap between the rate of return expected by the entrepreneur investing his own resources in innovation and the rate expected by external investors.[8] In other words, external investors usually charge higher interest rates for investing in innovation projects, in comparison with more conventional investments.

The reasons for this begin with the uncertainty surrounding R&D and innovation projects, where results and chances of success are hard to estimate, especially in the early stages of product development. Right now, for example, several pharmaceutical companies are researching potential treatments or even cures for Alzheimer's disease. Yet at this present stage, it is impossible to determine which of the technological trajectories emerging today will become viable. The new technologies and applications that could emerge from the prospects of gene editing are similarly still impossible to predict, even with all the information currently available. Uncertainty makes these investments riskier, thus raising the price charged by investors, as expressed by the interest rate.

8. Two recent studies produced an excellent review of the literature on the subject: Kerr and Nanda (2015), and Hall and Lerner (2010).

Furthermore, there is an asymmetry of information, in which the inventor usually has better knowledge about the prospects of innovation success than the investor. Because the investor has difficulty discerning the good projects from the bad, he tends to invest in those with lower risk, and to charge everyone a higher interest rate. In short, information asymmetry increases the cost of funding in innovation.

In addition, research investments rely heavily on highly trained and skilled staff. This kind of professional is not easily found in the market, which makes companies less willing to let them go in moments of economic downturn. Therefore, companies are inclined to smooth expansions and reductions in investments in R&D, generating higher costs of adjustment than that of conventional investment projects.

The banking system also tends to be less prone to fund innovation projects because of the loan collateral and escrows, which are typically actual assets rather than intangible assets. This reduces the funding options available to innovators, who ultimately depend more frequently on other sources of funding, such as personal assets, capital markets, or venture capital.

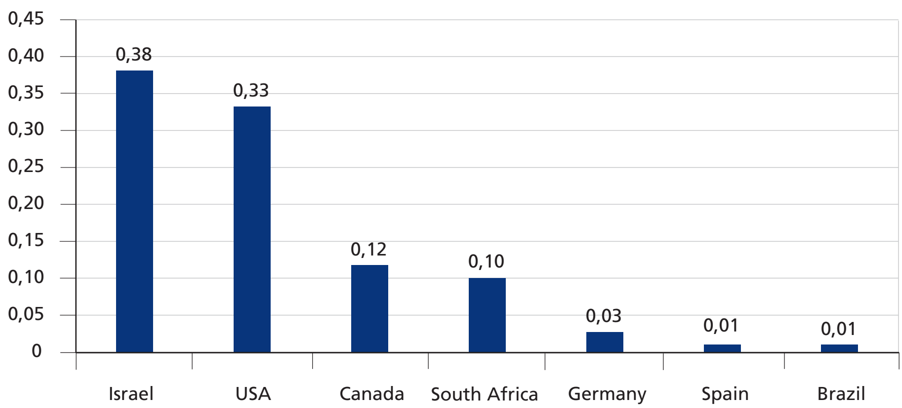
These are the reasons why investments in innovation have a higher cost in the market than conventional investments. As the literature shows, it is no coincidence that individuals usually put their own resources into this type of investment, rather than using other sources. Even so, several studies also reveal that, in recent years, the importance of credit in funding innovation has increased in several countries, and in some cases patents have been offered as collateral for these operations (Kerr and Nanda, 2015).

There are a few solutions to correct these market failures and reduce the interest rate gap for innovation. For instance, governments worldwide have been using tax incentives for investments in R&D to help reduce the cost of capital for innovation. Smaller companies and startups – which are most affected by funding constraints – do not benefit from this type of incentive. In their case, venture capital funds are the main instrument adopted to fund innovative projects.

These funds act as financial dealers specialized in innovation projects that, through constant scrutiny and monitoring, are able to minimize the information asymmetry between investors (venture capitalists in this case) and entrepreneurs. In general, these funds are aimed at young companies in sectors of substantial technological dynamism. The fund managers' constant monitoring and counseling also influence the company's governance and help improve its results.

Generally, this type of investment supports an idea right from the start, through a joint venture with the start-up business. This is usually temporary, however: investors sell their stake in the business at the company's Initial Public Offering (IPO) or even before it, to another possibly interested investor, or to the entrepreneur himself. Therefore, in order for the venture capital market to work, it is fundamental that venture capitalists find alternatives to drop out of the investment, which requires a relatively developed capital market for such startups.

CHART 4
Investments in venture capital in selected countries expressed as a proportion of GDP: South Africa (2015 and 2014) and Brazil (2013)
(In %)



Source: OECD, Cedro Capital, and Brazilian Association of Private Equity and Venture Capital (ABVCAP). Available at: <https://bit.ly/3ha3gYz> and <https://bit.ly/3hnnnS0>.

Chart 4 shows that, in addition to the difficulties created by the high interest rate, or to some extent because of the interest rate, the Brazilian venture capital market is still underdeveloped compared to leading countries in this sector. The leading country in this market is Israel, where these investments represent 0.38% of the GDP, followed by the United States, 0.33%. In Brazil, investments in venture capital correspond to merely 0.01% of GDP.

The high capital costs for investment in Brazil, combined with the even greater inherent costs of innovation projects, are therefore an important obstacle to innovation in the country. In addition to lowering interest rates, it is also necessary to reduce information asymmetries and other market failures that ultimately make the cost of innovation financing higher than that of conventional investment financing. Public funding may be one alternative, but it is not enough to overcome all of these obstacles.

4 BUREAUCRACY AND BUSINESS ENVIRONMENT

The openness of the economy and funding for innovation are, in isolation, probably the main environmental factors affecting innovation. However, a series of other factors also exist that make the economic context more or less conducive to innovation.

The World Bank analyzes several general factors, which it publishes in its well-known *Doing Business* reports. There is significant controversy surrounding this publication because it is often confused with a kind of competitiveness indicator. Despite methodological difficulties, what *Doing Business* intends to measure is merely the ease of doing business in a given country.

Basically, the annual report aims to assess the types of regulations companies must follow and what procedures they must adopt in order to operate (such as to start a business or pay fees and taxes); how well the country's legislation protects investors, especially minorities; and how effective the justice system is at resolving bankruptcies and other issues.

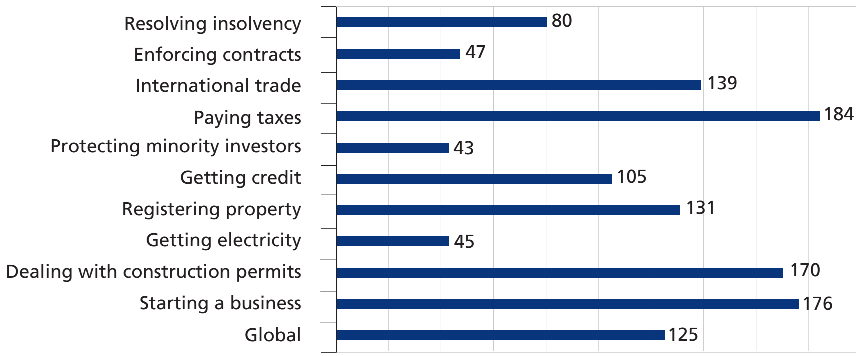
The importance of the business environment to economic performance gained prominence due to a 2002 study, in which the authors surveyed the time frame required and the costs associated with starting a company in several countries (Djankov *et al.*, 2002). They noted that processes that were more costly and bureaucratic were usually associated with greater informality and higher levels of corruption, in addition to a larger number of inefficient companies in the economy.

From this insight, the World Bank began calculating the indicators presented in the chart below, which shows Brazil's position in the ranking of various indicators measured by the *Doing Business* report.

Brazil's worst rankings are on the indicators dealing with permits, starting a business, and paying taxes, where Brazil falls below more than 170 countries. Even for the indicators where Brazil performs better, such as getting electricity, enforcing contracts, and protecting minority investors, it is still ranked behind more than forty countries.

It is worth noting that several countries are beginning to realize that an adverse business environment negatively affects business activity, reducing the efficiency of the economy in general. This perception has led to a convergence in the indicators of the *Doing Business* report; in other words, indicators are generally improving and all countries are moving closer to those most efficient. This has not been the case for Brazil, however. Our ranking and indicators remain steady or only slightly improved, as one Ipea study on productivity in Brazil recently revealed (De Negri and Cavalcante, 2014).

CHART 5
Brazil's position in the World Bank's ranking of the ease of doing business (2018)



Source: World Bank. Available at: <http://doingbusiness.org/data/exploreeconomies/brazil>.

The business environment affects economic activity in general, but it especially affects innovative activity. A large part of disruptive innovation comes from new companies, or startups. The more difficult it is for these companies to go into operation, the more difficult it is for certain innovations to reach the market. Brazil's business environment imposes barriers to launching new companies, which reduces the potential for competition and, as we have already seen, also negatively affects the country's innovation capacity.

In a 2015 publication, the OECD also drew attention, to how much the surrounding conditions affect a country's innovation capacity, particularly in a scenario of greater capital mobility between countries.[9] Among these conditions, a stable macroeconomic environment with low inflation and fiscal balance diminishes the uncertainty associated with new investments and, especially, with innovation.

For instance, the tax system can either foster or prevent certain types of innovation, such as offering tax breaks for R&D investment, exempting research institutions, or providing tax breaks for innovative products. As an example, the United Kingdom government taxes vehicles differently according to their level of CO_2 emissions in addition to lightly taxing vehicles that use alternative fuels.[10] This differentiated taxation obviously stimulates the production and commercialization of innovative, less polluting vehicles that feature emerging technologies, such as electric vehicles.

Government regulation of some markets also has the capacity to either stimulate or curb certain types of innovation. Brazil offers a very clear example

9. Available at: <https://bit.ly/3dBIuyS>.
10. Available at: <https://www.gov.uk/vehicle-tax-rate-tables>.

of how government intervention in markets can damage a country's innovation capacity: the basic production process (BPP), which is like a cake recipe that companies from the electronics sector have to follow to receive tax reductions on the production of certain goods. The production process of these goods must follow guidelines established by the Ministry of Industry, Foreign Trade, and Services. Now, generally speaking, to innovate implies making changes to the productive processes. It is clearly an anti-innovation regulation to, in a dynamic sector like electronics, require that companies' production processes be approved by government bureaucracy in order for them to retain tax benefits.

Currently, a market where regulation is becoming essential to enable technological advances is that of autonomous cars. Obviously, in order for this technology to be introduced in the market, it is necessary for legislation to permit a driverless car to travel on the streets and to specify how and to whom to apply sanctions in the event of an accident, or even to assess the safety of the vehicle. In February 2018, California anticipated this process and allowed circulation of autonomous cars on public roads within the state.[11] It is fair to assume that companies doing research on this type of technology will most likely build their research centers there.

Some economic conditions are even more related to the innovation process. Perhaps the greatest example is intellectual property rights and how they are regulated and guaranteed. Modern society developed intellectual property rights specifically to protect new ideas and their inventors. The objective is to assure innovators that they will receive an additional profit for a limited period of time, long enough to compensate them for the effort of innovating. Without this guarantee, a piece of innovation could be quickly copied by competitors and, in the long run, innovators would have no incentive to invest their funds and time in developing a new product or process. Brazil passed its patent law in 1996, in line with legislation applied in several other countries. However, one of the major hindrances in the country concerns the time it takes the National Patent Office (Instituto Nacional da Propriedade Industrial – INPI) to analyze a patent application, which can take up to eleven years in Brazil, according to a recent study comparing several countries.[12]

Other factors further hamper research and innovation in Brazil. In a closed economy like ours, importing research equipment and supplies can be an even greater nightmare than importing regular goods and equipment. Research institutions and universities are less familiar with the bureaucratic procedures associated with importation, which is likely to aggravate the situation. Yet the

11. Available at: <https://www.nytimes.com/2018/02/26/technology/driverless-cars-california-rules.html>.

12. Available at: <https://bit.ly/3ha3z5F>.

vast majority of equipment and research inputs have to be imported, as evidenced by a survey conducted by teachers from Universidade Federal do Rio de Janeiro (UFRJ), which revealed that 99% of researchers need to import this type of product.[13] Even worse is that 75% of the researchers surveyed stated they had lost research materials at customs. In some areas, such as the life sciences, much of the imported research material is perishable, requiring an agility that Brazilian customs procedures seem to lack.

Sensible public intervention on such issues would help create a more conducive environment for innovation. There are various aspects that have to go through the efficiency of some government agencies, or through a ton of legal and regulatory paperwork, making it difficult to draw consistent strategies to improve the business environment. However, these are issues that largely hinder the activities of companies and institutions and strongly impact their performance, especially regarding innovation, where agility and flexibility are fundamental.

13. Available at: <https://pt.scribd.com/document/41403849/Pesquisa-Importacao-07112010>.

CHAPTER 5

INVESTMENT AND PUBLIC POLICIES

1 INTRODUCTION

From an economic standpoint, science and knowledge can be considered public goods. A public good is provided for common use, meaning that its use by one individual does not prevent others from also using it. The fact that someone uses acquired knowledge – that HIV is the virus that causes AIDS, for instance – does not prevent others from using the same knowledge for different purposes. It is different than using a car, wearing clothes, or having coffee, because our consumption reduces the amount of those goods available to other people. This is not the case with knowledge. Knowledge does not diminish when someone makes use of it. In addition, it is not possible for one "consumer" to prevent other people from having access to the same scientific knowledge. Knowledge, unlike a consumer good, is not intended for the exclusive use of a single person.

Beyond the characteristics of a public good, scientific knowledge has other important characteristics that make it particularly important within the scope of public policies. Science generates positive externalities for society as a whole. This means that knowledge production generates benefits not only for those who produce it or pay for its production, but for society as a whole. We all benefit to this day, for example, from Alexander Fleming's discovery of penicillin. Moreover, the social benefits of scientific discoveries tend to be infinitely greater than their cost.

All of these characteristics, especially the positive externalities generated by science, make scientific knowledge a "good" of particular interest to society. But these same characteristics reduce private companies' interest in producing it. What interest would a company have in investing in the production of goods that will ultimately be public? If it is impossible to restrict access to a certain good (through imposing a fee), that is to say, if a good is freely available to anyone, then a company will never profit from producing it.

This is the reason why, across the world, governments are the predominant funders of scientific production. Although there are some cases of corporate funding for basic research, companies mainly invest in applied research and product development. However, the distinction between basic and applied research is becoming less clear. The main difference is perhaps that companies fund research that can ultimately produce private goods, that is, that can result in technologies, products, or processes that prove profitable for the company.

Innovation, on the other hand, depends on private sector funding, but also demands consistent public support. Innovation also produces positive externalities. The discovery of a new drug is an innovation that offers benefits for the company that developed the product, while offering even greater social benefits. These positive externalities help attract the interest of society in funding innovation, even though part of the gains from such innovation may have to be shared with the innovators. Moreover, there are also market failures, including those mentioned previously, which can make market-induced innovation investment less socially desirable.

Thus, in addition to direct funding of science and innovation, the government should intervene in the aforementioned factors impacting the country's innovation capacity, namely: i) scientists' education and training; ii) research infrastructure; and iii) an environment conducive to innovation. Accordingly, this section will discuss how public policies can boost innovation, and which policies have recently been adopted in Brazil.

2 WHO FUNDS SCIENCE?

The answer to the question above is fairly simple: we all do. Most of the funding for science worldwide comes from governments. This means that society, for all its limitations and idiosyncrasies, decides to allocate part of its income and its taxes to fund scientific endeavors. This is another reason why scientists should be constantly concerned with societal challenges and the legitimacy of scientific investments. Unfortunately, some members of society remain unaware of the extraordinary results humankind has achieved thanks to science.

At this point, some of you might be asking, in developed countries, is it not the private sector that funds much of the scientific research. As argued above, this perception is not accurate. It is true that, in developed countries, investments in private sector research are larger and reflect a larger share of total research efforts than in developing countries like Brazil. In general, however, companies fund research and development (R&D) activities to convert scientific knowledge into new products and services, which is an essential part of innovation. The production of scientific knowledge, however, depends heavily on public funding. We will turn to the numbers, but first, let me offer some clarification.

When we talk about funding for higher education and research, at least three models with quite different dynamics exist. First, the type of education designed exclusively for training highly qualified professionals who are not engaged in producing research. Funding, in this case, could be provided either by the state or by the students themselves, by means of tuition or some hybrid alternative that combines different sources of resources. These models vary based on the history of each country, as well as their options to guarantee universal access to quality education. But this model of education is not our primary concern in this section.

Second, there are the so-called research universities, active in both training future professionals and in knowledge production. Across the world, these universities are much more expensive and dependent on public funding than those devoted exclusively to education. While many rely on diverse sources of funding, including tuition, the most relevant source is public funding.

Take the United States, for example, where many believe that private funding for science is most important. The first lesson to draw from chart 1 is that the income sources of United States higher education institutions are quite diverse and vary widely according to the type of institution.

Private for-profit institutions are primarily funded by tuition and fees paid by students. These types of schools focus almost exclusively on education and are of little relevance to the United States system, besides performing more poorly than other institutions. At these for-profit institutions, public resources account for only 4% of total revenues.

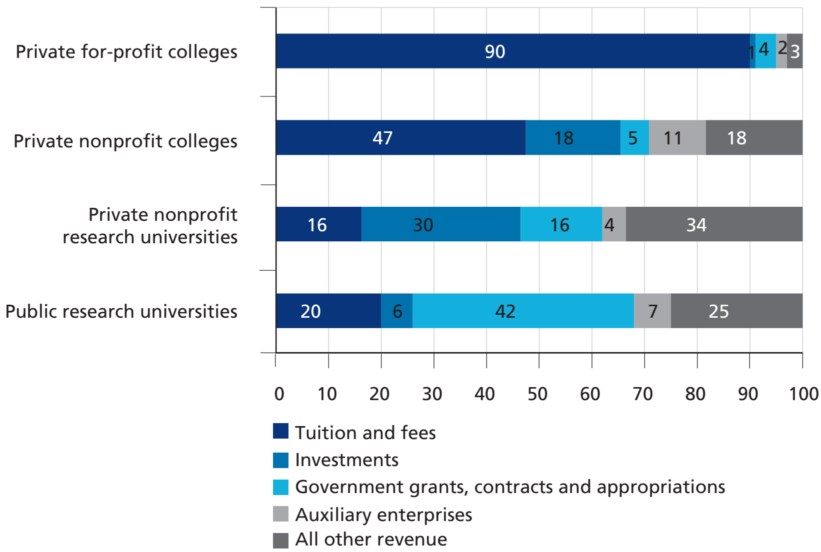
Historically, among private institutions, nonprofits have greater relevance in the United States educational and research system. Chart 1 divides them between research universities and other HEIs. Private non-profit HEIs not classified as "research" are, in general, more focused on teaching, despite also having some research activity, and training for master degrees and PhDs. Similar to their for-profit peers, these institutions rely very little on public funding.

In contrast, institutions classified as research universities – whether private or public – possess a high level of scientific research, according to the NCES. As a result, these are the institutions we will focus on in this work.[1] Harvard University, the Massachusetts Institute of Technology (MIT), Columbia University, the California Institute of Technology (Caltec), and many other renowned United States universities are research universities.[2] At private research universities, the largest source of income comes from investment funds (endowment funds), often built from donations, and which reflect about 30% of the income of these universities. Tuition accounts for 16%, and public funding accounts for another 16%. For public universities and colleges, as one might expect, the largest share

1. Details on United States universities' funding can be found at Turchi (2014).
2. Available at: <https://en.wikipedia.org/wiki/List_of_research_universities_in_the_United_States>.

of revenue comes from state, local, or federal governments. However, even these institutions receive funding from many sources, reaffirming that United States universities are relatively financially sound institutions.

CHART 1
Revenues of United States higher education institutions (HEIs) by institutional control and source of funds (2015)
(In %)

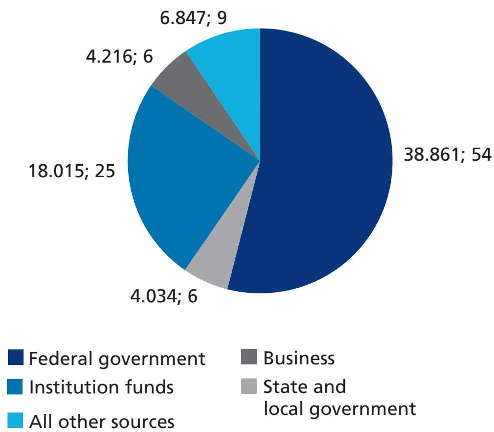


Source: National Center for Education Statistics (NCES).
Obs.: Data for private non-profit institutions were compiled from the tables available at: <https://nces.ed.gov/programs/digest/2016menu_tables.asp>. For private for-profit universities and for public universities, data refers to 2014 and is available at: <https://nces.ed.gov/programs/coe/pdf/Indicator_CUD/coe_CUD_2016_05.pdf>.

Funding sources not shown in chart 1 include revenues from college hospitals, donations, private companies, research grants from private foundations, and university services for students or the general public (health clinics, housing etc.).

These numbers represent the total revenue of United States universities and colleges and are used to cover the costs of teaching, research, and other possible activities carried out by the institutions. However, when we look specifically at universities' research expenditures, the share contributed by public resources exceeds 60%, as shown in chart 2. In 2016, United States universities invested more than US$ 71 billion in research, of which more than US$ 42 billion was funded by either the federal or state and local governments. Another 25% of total research expenditures, on average, come from institutions' own resources. For private nonprofit universities, as we saw above, this tends to come from endowment funds and tuition fees. In the case of public universities, resources are most likely to come from tuition fees or from the institution's own budget, which is public. Thus, contrary to common perceptions, the science produced in United States universities depends heavily on public resources.

CHART 2
R&D expenditures in United States universities, according to source of funds (2016)
(In %)



Source: National Science Foundation (NSF), National Center for Science and Engineering Statistics, Higher Education Research and Development Survey. Available at: <https://ncsesdata.nsf.gov/herd/2016/html/HERD2016_DST_01.html>.

One concrete example of the relevance of public funding for research is a top university in the United States and in the world, MIT. Federal grants and research contracts constitute more than 40% of the university's total revenue, and almost 90% of its research revenues.[3]

Other countries follow the same norm. At Oxford University in England, about 50% of the institution's total revenue is derived from the British government. In Germany, where all universities are public, that figure could be even higher. At the Technological University of Munich, for instance, more than 60% of current revenue comes from the government. Regarding research funding alone, the government is unquestionably the major funder in these two countries. In England, on average, 66% of university research revenues come directly from the British government and another 11% come indirectly from the European Union. Thus, about 77% of the funding for academic science in the United Kingdom comes from public sources.

3. Included in the list is the Lincoln Lab, an MIT-based laboratory, which is fully funded by and for the exclusive use of the United States Department of Defense, and accounts for more than half of the research spending. The average spending (payout) rate from endowments in 2014 was 4.4%. MIT available at: <http://web.mit.edu/facts/financial.html>.

It is important to reiterate that private companies are not providing the most significant resources and funding for research in United States universities, as this fact is contrary to common belief. According to the NSF, as laid out in chart 2, only 6% of total research funding at United States universities comes from research contracts with private companies. Even at technology-oriented institutions such as MIT, funding from business sources accounts for less than 10% of the research budget, and less than 4% of the total budget. Examples from other countries also point in the same direction. At the Technological University of Munich, company-sponsored research accounts for about 5% of the institution's revenues; while at Oxford University, it accounts for just over 1%.

However, as we discussed, another relevant source of funding for United States universities is endowments. Endowments primarily consist of investment funds, the income of which is used for the maintenance of universities, although they may also include real estate and other assets. Endowments account for only 6% of public universities' revenue in the United States, but they account for 30% of private nonprofit universities' income and fund a large share of the research conducted at these institutions. In general, a university's endowment fund consists of hundreds of individual funds. At Harvard, for instance, there are more than 13,000 different funds managed by a non-profit corporation created by the university specifically for that purpose: the Harvard Management Company (HMC).[4]

In general, these funds are built of individual donations from alumni, entrepreneurs, or citizens over the years or even the centuries, in some cases. Henry VIII of England created the first endowment to fund the universities of Oxford and Cambridge. Harvard University has accumulated a US$ 36 billion endowment fund over its nearly four centuries. It is by far the largest endowment out of all United States universities and its income reflects about 30% of the institution's annual budget. In public universities, such as the University of California Berkeley, endowment income contributes, on average, 5% of their annual revenues.

In the United States, several tax benefits encourage the formation of and donation to these endowments. First, as in Brazil, private non-profit educational institutions do not pay taxes. In the United States, income from endowment funds owned by nonprofit universities and research institutions are also exempt from paying income tax.[5] Second, donations to these funds are tax detectable, meaning that donors can deduct the amount to reduce their taxable income.

4. Available at: <https://www.harvard.edu/about-harvard/harvard-glance/endowment>.

5. At the end of 2017, the Trump administration approved a 1.4% tax rate over the profitability of endowment funds whose value per student exceeds US$ 250 thousand. This was seen as an attempt by the Republicans to weaken major centers of liberal thought in the United States.

Given the size of these funds, these tax incentives represent billions of dollars provided by the United States government to incentivize alternative sources of revenue for universities.

A study conducted by the United States Congressional Research Service showed that by 2014 the total sum of endowment funds from United States universities amounted to more than US$ 500 billion, with 11% of the institutions accounting for 74% of all assets.[6] On average, the funds yielded more than 15% per year, with between 4% and 5% of the value of the assets (only a portion of the earnings, therefore) used by universities. The rest remains in the fund, increasing the size of the endowment.

In 2008, France passed its Law of Modernization of the Economy, which (along with other measures to improve the country's business environment) established endowment funds as legally-recognized entities, inspired by the United States endowment model. Under the law, these funds are private nonprofit institutions that receive and manage donated assets and the derived rights, and utilize the income from these investments to execute missions and tasks in the public interest.[7]

In Brazil, this type of fund is just beginning to appear. The Friends of Poli Fund, an association that supports projects at the Polytechnic Institute at the University of São Paulo was one of the first. Created in 2011, it now has a net worth of just over R$ 20 million. Nonetheless, several legal and cultural obstacles still exist in Brazil, given that donations to universities are not common. Fund managers argue that the existence of a specific legal framework for this type of fund could help its development and provide greater safety to donors.[8]

This could provide an additional source of funds for Brazilian universities, especially considering the funding crisis that these institutions are facing. There has been a significant rise in the number of higher education institutions and universities in the country in recent years. From 2000 to 2013, both the federal and state governments created 89 new institutions of higher education, most of them universities or technological centers, a growth rate of over 150%. On the one hand, this growth has contributed to greater access to higher education. On the other hand, it introduced a change in the budget allocation required to maintain the country's public higher education institutions, which in turn has jeopardized its capacity to finance them and, consequently, has threatened their quality.

6. Available at: <https://fas.org/sgp/crs/misc/R44293.pdf>.

7. Available at: <http://ernop.eu/wp-content/uploads/2017/06/Truffinet-Endowment-Funds-in-France.pdf>.

8. Available at: <http://economia.estadao.com.br/noticias/geral,fundos-de-doacoes-avancam-no-pais-imp-,1524740>.

Thus far, we have examined institutions predominantly focused on teaching and research universities. In addition to these, there are institutions focused primarily or exclusively on research. The financing model for these institutions varies largely depending on the type of research being conducted. In general, institutions that are oriented to produce applied research or product and process development – such as the Fraunhofer in Germany – receive a greater volume of private funding.

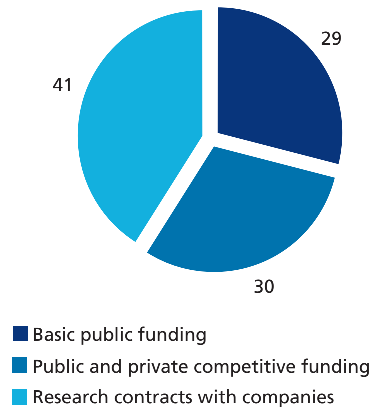
Institutions more focused on basic research, such as several of the United States national laboratories, tend to rely on public resources. Although these laboratories have outsourced management to private non-profits, companies, or universities, they are fundamentally dependent on public resources. In 2016, the so-called Federally Funded Research and Development Centers (FFRDCs) invested more than US$ 19 billion in research, with 98% of that amount funded by the federal government, especially, by the Departments of Energy and of Defense.[9] The same is true in other countries. The Max Planck Institute in Germany, for example, relies heavily on federal and state budgets, which account for more than 90% of the institution's total annual revenues.[10]

Private funding is more heavily involved in financing S&T in the case of applied research institutions or technological institutions. These institutions are also known as Research and Technology Organizations (RTOs). According to the European Association of Research and Technology Organizations (EARTO) the mission of these institutions is to take advantage of advances in S&T for innovation, to improve the quality of life and stimulate economic competitiveness. Examples of such institutions are the Fraunhofer in Germany, and the National Research Councils in Canada.

Although the institutions are focused on applied research and innovation, public funding is still crucial. According to the EARTO data presented in a recent study by MIT researchers, about 41% of these institutions' funding comes from contracts with private companies (Martínez-Vela, 2016). Of the remainder, part comes from basic public funding, and the other part from public and private competitive grants, meaning institutions have to compete to gain financial support for specific projects (chart 3).

9. Available at: <https://ncsesdata.nsf.gov/datatables/ffrdcrd/2016/html/FFRDCRD2016_DST_1.html>.
10. Available at: <https://www.mpg.de/11359014/annual-report-2016.pdf/>.

CHART 3
Sources of funding for institutions linked to the EARTO (2015)
(In %)



Source: EARTO.
Elaborated by Martínez-Vela (2016).

3 POLICIES FOR S&T IN BRAZIL

Over the past fifteen to twenty years, Brazil has undertaken a series of measures intended to strengthen the country's scientific, technological, and innovation capacity. These measures include direct financial support for investments and research in universities, research centers, and companies; credit for corporate investments in R&D; tax incentives for corporate investments in R&D; and a number of regulatory measures. Among the policies pursued are, for instance, the creation of the Sectoral Funds, the Innovation Law (Law nº 10,973 of December 2004), and the Lei do Bem (Law nº 11,196 of November 2005, whose name roughly means "Law for the Good").

The Innovation Law provided rules for the participation of researchers from public institutions in corporate projects, and for the commercialization of intellectual property resulting from this kind of partnership. In this regard, the law has encouraged the public and private sectors to share staff, resources, and facilities, in order to stimulate collaboration between universities, research institutes, and private companies. Another significant advancement of the Innovation Law was the possibility for the state to subsidize R&D investments in private companies, which was not previously allowed under the Brazilian legal framework. The Lei do Bem, on the other hand, broadened the scope and facilitated the use of fiscal incentives to realize private investments in R&D.[11]

11. The first attempt to adopt tax incentives in Brazil concerned both the Industrial and the Agricultural Technological Development Programs. The requirements for taking advantage of these programs (such as the obligation of having a project approved by the Ministry of Science and Technology to become eligible to the tax incentive), however, have rendered them practically meaningless.

These efforts in formulating new policies, plus pre-existing initiatives (the Sectoral Funds are just one example), have built a relatively comprehensive framework of innovation policies, in terms of its diversity of instruments. In other words, despite the absence of initiatives on the demand side, Brazil now features many of the instruments used in most developed countries to foster innovation, such as: i) subsidized credit; ii) tax incentives; iii) subsidies for enterprises; and iv) grants for research projects in universities and Science and Technology Institutions (ICTs), among others.[12]

The main support mechanisms for science, technology and innovation at the federal level currently in effect in Brazil are shown in table 1, which sums up key Brazilian public policies clearly impacting the country's innovation output.[13] These are the principal sources of funding supporting innovation and R&D in the country. Some of the funds described below are not strictly public and some are not budgetary appropriations. The values assigned to credit policies, for instance, reflect the total availability of credit for innovation at Brazilian Development Bank (Banco Nacional de Desenvolvimento Econômico e Social – BNDES) and Financial Backer for Studies and Projects (Financiadora de Estudos e Projetos – FINEP), not the fiscal cost associated with equalizing interest rates for these programs. Likewise, the resources associated with compulsory investments in R&D in regulated sectors reflect the total R&D investment obligations under the responsibility of regulated companies, and thus correspond to private resources compulsorily allocated to R&D.

In 2015, the federal government allocated more than R$ 50 billion to different policy instruments such as tax exemptions, credit, direct investment, and regulation, to be applied to S&T activities.[14] The most significant share of this money – around R$ 33 billion – was for direct investment in S&T activities by the federal government. Of this amount, nearly R$ 10 billion went not to research but to expenses involved in the maintenance and operation of postgraduate courses in Brazil, that is, money spent on training new scientists. Therefore, nearly R$ 24 billion are left for direct investment in research.

12. Innovation policies addressing demand are intended to create conditions for stimulating and increasing the demand for innovations. While supply-side policies are concerned with securing the material and immaterial resources necessary for the development and introduction of innovations by firms, demand-side policies are concerned with "pulling" the supply of specific technological developments through the creation and/or direction of needs. The most obvious facet of such innovation policies aimed at the demand regards the use of the state purchasing power.

13. This table was originally published by Zuniga *et al.* (2016), with data up to 2012.

14. The absence of current data regarding ANEEL's R&D does not allow a precise estimate. Nonetheless, judging by the behavior of this variable in the period 2001-2012, the participation of that group in the total budget allocated by the federal government will continue to be marginal and the actual total of this allocation will be very similar to what is presented here.

TABLE 1
Major federal policies or instruments aimed at supporting Science, Technology, and Innovation in Brazil (2015, or last year available)

Policies	Instruments	Amount in millions of R$ from 2015
Tax exemption[1]	Computer Law (nº 8,248/1991, nº 10,176/2001 and nº 11,077/2004)	5,022
	Good Law (Law nº 11,196/2005)	1,835
	Research, development and innovation (RD&I) in the auto sector (acts nº 12,407/2011 and nº 12,715/2012 and Decree nº 7,819/2012)	2,850
	Others exemptions[2]	877
Subsidized credit for innovation (down payments)	Operated by FINEP	2,603
	Operated by BNDES[3]	4,501
Public investment in S&T	Federal government total expenditure towards R&T	33,845
Regulated sectors mandatory R&D	R&D Brazilian Electricity Regulatory Agency (Agência Nacional de Energia Elétrica – ANEEL)	3,92[4]
	R&D National Petroleum Agency (Agência Nacional do Petróleo – ANP)	1,030

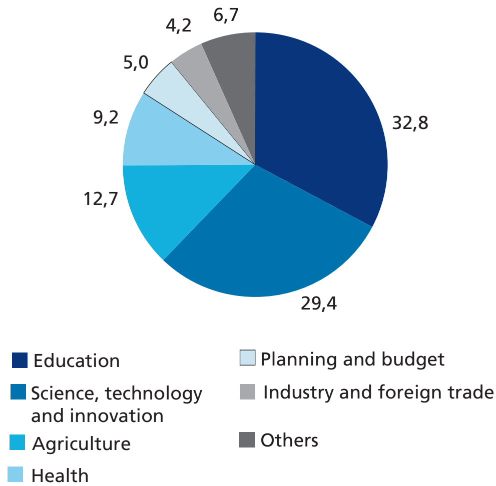
Source: Ministry of Science, Technology and Innovation (Ministério da Ciência, Tecnologia e Inovações – MCTI); BNDES; FINEP; CGEE (2016); ANP.
Elaborated by Zuniga (2016).
Notes: 1 Estimates made by the Brazilian Federal Revenue Service. Available at: <https://bit.ly/363VtVK>.
2 Scientific non-profit entities, machinery, and equipment – Brazilian National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq).
3 Amounts for FINEP were excluded.
4 Data from 2012 made available by CGEE (2016).

The rough distribution of these resources among the different ministries is shown in chart 4. The largest share of this budget is allocated to the Ministry of Education and funds undergraduate and postgraduate scholarships at both Brazilian and foreign universities: hence, training scientists. The second largest share, at almost 30%, is allocated to the MCTI.[15] Only then, at a distant third and fourth, are the S&T budgets given to the Ministry of Agriculture and the Ministry of Health.

This distribution already differentiates investments in S&T in Brazil from those in the United States. In the United States, about 80% of investments in R&D are carried out by three federal agencies: Defense (nearly 50%), Health (20%) and Energy (10%). Despite these agencies' extensive investments to fund basic research, this distribution reveals that investments in S&T are more oriented toward solving complex technological issues in the areas of defense, health, and energy. In contrast, Brazilian investments in S&T are not what the literature refers to as "mission-oriented" investments, in the sense that most of these investments are not associated with ministries or departments with a specific mission, unlike in a number of other countries (Mowery, 2009).

15. The data from 2015, so the corresponding Ministry at the time excluded the Communications sector.

CHART 4
Distribution of the federal budget for S&T, among several ministries (2015)
(In %)



Source: MTIC.

Investments in S&T for a specific mission are evident in the Ministry of Agriculture, which invested almost R$ 3 billion in S&T in 2015, and in the Ministry of Health, with over R$ 2 billion invested. Two research institutions account almost this entire investment: the Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária – Embrapa) and the Oswaldo Cruz Foundation (Fundação Oswaldo Cruz – Fiocruz).

Embrapa is the heart of a national system of agricultural research responsible for technological advancement, including those that made possible, among other things, the cultivation of soybeans in a climate poorly suited to the activity, as in the Brazilian *cerrado* (the vast tropical grasslands covering the center of Brazil). Fiocruz similarly has the straightforward mission of developing technologies to strengthen the Brazilian health system (Sistema Único de Saúde – SUS) and to promote health and quality of life among the population. The institution has a broad scope, from education to basic and applied health research. Both Embrapa and Fiocruz conduct their research internally, through their own researchers and laboratories.

Historically, the Ministry of Science and Technology (later called Science, Technology and Innovation), has been the main source of funding for scientific and technological research in the country. The MCTI makes direct investments through its research units or affiliated institutions, through CNPq's research and graduate scholarships, or the Brazilian National Fund for Scientific and

Technological Development (Fundo Nacional de Desenvolvimento Científico e Tecnológico – FNDCT). The largest portion of the MCTI's budget was allocated to the FNDCT, which in turn became the main source of financing for the work of Brazilian scientists and researchers. As illustrated in the next section, this fund has suffered a significant reduction in recent years.

In short, since the early 2000s, the resources available for innovation as well as the regulatory framework have been expanded and improved. From the scientific perspective, one of the results, as we have seen, was the increase of our participation in global scientific production. From the perspective of innovation, the results were not as significant despite growth in the number of companies supported by innovation-oriented policies and R&D. In fact, the number of innovative companies that reported receiving some public support to innovate rose from 19% in 2003 to nearly 40% in 2014, according to data from Brazilian Institute of Geography and Statistics' (Instituto Brasileiro de Geografia e Estatística – IBGE) survey on technological innovation. However, it is important to note that most of the public support was linked to BNDES programs to finance machinery and equipment, which were not specifically designed for innovation. Looking at just the companies that declared receiving support from innovation-oriented public policies, we see that the number also increased, but on a much smaller scale: it went from 4.6% to 8.6%, in the same period.

In spite of the expansion and consolidation of a series of public policies for S&T, the most significant indicators – private investment in R&D, patent filings, the innovation rate, and high technology exports – show only modest effects. This suggests that, in addition to the other factors that impact Brazil's innovation capacity, these policies also ought to also be rethought and improved.

4 STABILITY AND DIVERSITY IN PUBLIC FUNDING FOR S&T

One of the main desirable features of public investment in S&T is predictability. The results of investing in science do not emerge overnight: they require time and persistence. Large-scale scientific projects are long-term pursuits that require collaboration among different institutions, and which often need to be developed in stages. For this, several years of stable and predictable investment are needed.

A cancer researcher in the United States, for example, knows that the National Cancer Institute – part of the National Institutes of Health (NIH) – has an annual budget of nearly US$ 5 billion, and that budget has been the same for the past ten years and will remain so in the coming years. This researcher may feel encouraged to start a long-term research project because he knows that if the project proves competitive and progresses satisfactorily, he will have a good chance of receiving future support for a next phase.

Research conducted on health or climate change are good examples of the long timeframe often required to achieve important results. To study how eating habits influence quality or life expectancy, for example, it is necessary to follow groups of people with different eating habits and to monitor their health indicators over time, often for decades. The Human Genome project, for example, which involved researchers from around the world, was planned as a 15-year research effort. Monitoring the activity of volcanoes, studying of the Sun, and measuring the effects of fertilizers on crop productivity are just some examples of long-term research projects, all cited in *Nature* report in 2013.[16]

In Brazil, stability and predictability have never been strengths of S&T policies. Providing a stable and predictable source of funding for Brazilian S&T was, incidentally, one of the reasons behind the creation of the Sectoral Funds (which became FNDCT) in the late 1990s. The Funds were to have been composed of taxes and contributions from several industries (hence the name Sectoral Funds), with oil and gas royalties to become the main source of revenue over the years. This way, it would be possible to predict slight fluctuations in funding for S&T, according to the level of economic activity, and therefore, funding for scientific and technological research would be guaranteed.

What happened over time, however, was that as the revenue from sectoral funds grew, the government lowered the baseline budget of the Ministry of Science and Technology. For this reason, even during years in which the overall budget for S&T grew (and it grew significantly until 2014), the Ministry's relative share of the total federal appropriations remained stable. This was the conclusion of a study carried out by the monitoring and evaluation department of the Ministry in 2011. In spite of this, the overall budget of the Ministry grew significantly from 2000 to 2014 (chart 5), following the general trend for public spending. As a result, the scientific community noticed a significant increase in the provision of resources for investment in research in universities and research institutions.

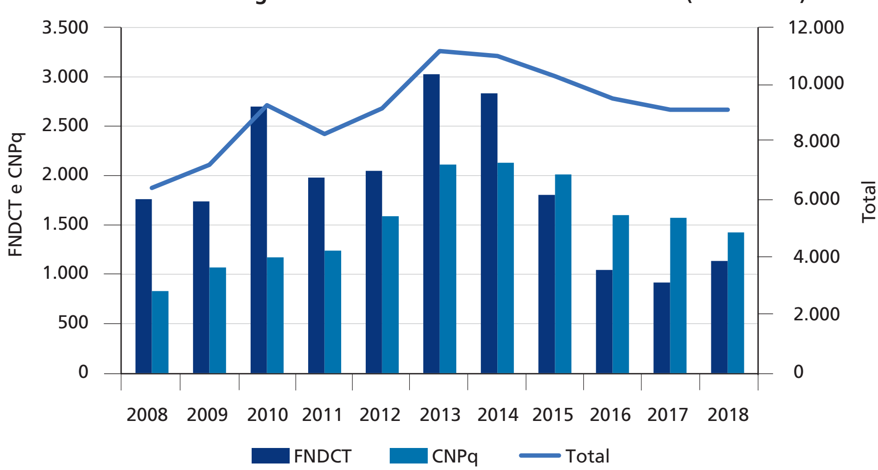
Although its effects were only felt much later, the major blow to the Brazilian S&T budget was the oil legislation passed in 2013 (Law nº 12,858/2013). The law reallocated royalties originally earmarked for the Oil Sectoral Fund (CT-Petro), which accounted for most of the Sectoral Funds' revenue, to the areas education and health. In 2013, for example, CT-Petro accounted for 31.4% – nearly US$ 380 million (R$ 1.4 billion) – of the total revenue of the Sectoral Funds. The loss of the royalties represented a major loss to S&T funding in Brazil in the long run.

16. Available at: <https://www.nature.com/news/long-term-research-slow-science-1.12623>.

It is no coincidence that in absolute terms the Ministry's budget, just like its main components, has fluctuated considerably, as shown in chart 5 (which includes, as part of the line marked "total," the Ministry of Communications). The two main budget components of the Ministry of Science and Technology are the FNDCT and the CNPq. These two are the main sources of funding for Brazilian science. The budget bill proposed for 2018 reduced CNPq's appropriates by more than 30% compared to what was allocated in 2014. The actual reduction could be even greater, since budget appropriations are never disbursed in full, especially in periods of fiscal tightening. And the reduction to the FNDCT was even larger. The FNDCT budget for 2018 is about 60% lower than the one passed in 2014. Oscillations of such proportion for the main source of science funding are incompatible with the predictability needed for R&D spending and to maintain the quality of scientific research in the country.

In addition to these brutal oscillations, the S&T budget also suffers from the lack of continuity between governments and their priorities. A clear example of this is how the FNDCT was handled in recent years, given that its priorities and allocation of resources were altered either to comply with short-term, contingent public policies, or to replace resources of programs that should be funded by other sources.

CHART 5
Evolution of the budget of the MCTI and its main ramifications (2008-2018)



Source: Integrated System of Budgeting and Planning (SIOP).
Obs.: For 2016, the total reflects the sum of the budgets of the MCTI. For 2017, the value already reflects their fusion.

The Science without Borders Program, created in 2011, deserves a mention for both its merits and its problems. Its merit lies in the fact that the program represented a big step towards the greater internationalization of Brazilian science, particularly in the areas of science, technology, engineering, and mathematics. Nonetheless, the ambitious goal of sending 100,000 students overseas eventually compromised the program and overshadowed its initial merit. In order to fulfill its goal, the program sent an excessive number of undergraduate students sent abroad, which meant students were placed in lower quality institutions. In addition, the program was created without a corresponding source of funding, which overwhelmed the FNDCT. According to the budget data for 2014 and 2015, Science without Borders was largely funded by the FNDCT – nearly US$ 250 million (R$ 900 million) in 2014 and US$ 270 million (R$ 1 billion) in 2015 – which in turn diverted resources from the research projects and other investments typically funded by FNDCT.

In addition to instability, it is worth mentioning the lack of diversity in the way we support science and technological production in Brazil. The principle source of funding for S&T, the FNDCT operates by awarding grants (non-reimbursable resources) for scientific research developed at universities (sometimes in partnership with companies) and at companies. CNPq and Coordination for the Improvement of Higher Education Personnel (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Capes) award scholarships and aid (in the form of grants) to support students and, on a small scale, to fund research projects. FINEP and BNDES offer credit lines to encourage companies to innovate. In addition, part of Brazilian investment in S&T goes directly to public research institutions linked to the MCTI, in addition to Fiocruz and Embrapa.

In short, the S&T investment model adopted in Brazil consists of awarding grants, offering lines of credit, or undertaking research directly; and the model is highly centralized around the MCTI. The recent creation of Brazilian Company of Research and Industrial Innovation (Empresa Brasileira de Pesquisa e Inovação Industrial – Embrapii), a social organization linked to MCTI, marked the adoption of a slightly different model, inspired by the Fraunhofer Foundation. Projects can receive a public grant through Embrapii, but in order to qualify, they show that the project has also secured funding from the private sector and from the research institution that carries on the project. Each of the three should cover approximately 1/3 of the total project. Therefore, the public sector reduces the risk to the private agent and encourages further investments in innovation.

We can once again take the United States model as an example, where the diversity and decentralization of the S&T support system are striking features. According to De Negri and Squeff (2014a), the United States government invests in S&T in a variety of ways:

- directly, through research institutes and federal laboratories linked to several government departments, such laboratories linked to the armed forces, the NIH, and laboratories linked to National Aeronautics and Space Administration (NASA), among others;

- directly, in Federal Funded Research and Development Centers (FFRDCs) that, although federal laboratories, are operated privately by companies, universities, non-profit institutions, or consortia of these institutions;
- indirectly, through non-reimbursable grants awarded to both researchers and companies. Grants are awarded through public, competitive processes and serve as a support mechanism for R&D by various agencies and departments. They are flexible instruments, in that the researcher is not expected to deliver any result except perhaps a final report;
- by means of cooperation agreements, which is an intermediate instrument between a grant (where no concrete deliverables required of the researcher) and a contract (where the anticipated products are well-defined); and
- by means of R&D contracts, wherein the government outsources technological development for products or services to be used by the country. Unlike in Brazil, R&D contracting in the United States is explicitly covered in public procurement law, under the Federal Acquisition Regulation (FAR). FAR requires that "the primary purpose of contracted R&D programs is to advance scientific and technical knowledge and apply that knowledge to the extent necessary to achieve agency and national goals".[17] Consequently, contracts should be limited to the purchases of products or services for the federal public administration. On the other hand, when the main objective is to encourage or support research and development, FAR states that grants or cooperation agreements should be used.

In short, there are a number of methods and mechanisms through which the United States government invests in R&D. In addition to the items discussed above, there are a number of other aspects that differentiate the way in which the various federal departments and agencies invest in R&D, which makes the United States system extremely complex and diverse. The way each of them operates is very specific and closely associated with the mission and the main goal of each department or agency. The table below summarizes some of these differences, and how they relate to the type of research supported, using data extracted from a recent study by Ipea.[18]

17. Available at: <https://www.acquisition.gov>.
18. De Negri and Squeff (2014b).

This diversity in the different forms of supporting science is, therefore, a way to achieve different goals. In general, awarding grants is an example of basic research support associated with more risk and less government control. At the opposite end, when the development of products is required, the most common method is contracting.

TABLE 2
Major agencies and ministries that invest in R&D in the United States, and its main features

Agency/department	Main focus	R&D activity	Mode of operation
Department of Defense	Very specific	Development and engineering	Primarily contracting
Defense Advanced Research Projects Agency (DARPA)	Specific	Development and applied research	Grants and contracting
Department of Energy	Broad	Basic (main) and applied research	Grants and contracting with FFRDCs
Advanced Research Projects Agency-Energy (ARPA-E)	Specific	Applied research	Grants and contracting
NIH	Broad	Basic and applied research	Grants
NASA	Very specific	Basic and development research	Contracting
NSF	Very broad	Basic research	Grants

Source: De Negri and Squeff (2014b).

These instruments also vary by agency: those with a more specific focus tend to opt for contracts while larger funding agencies tend to opt for grants. Brazil should develop more comprehensive and diversified S&T support strategies as a way to improve the effectiveness of its policies.

CHAPTER 6

INNOVATION IN HEALTH

1 INTRODUCTION

In general, innovation in the health sector – whether regarding drugs, devices, or medical equipment – requires the very same conditions and is influenced by the same factors as any other sector. In other words, innovation demands skilled people, adequate infrastructure and a favorable environment. However, some of these conditions have a bigger impact on health innovation because of the specific characteristics of this area, making the innovation process even more complex than in other sectors.

What are these characteristics? First, health innovation is probably much more science-intensive than any other sector. Several examples cited throughout this work point to a connection between basic science and health innovation. It is no coincidence that one of the world's leading centers of health research is located in and around Boston – home to a host of world-renowned universities and research centers such as Harvard and Massachusetts Institute of Technology (MIT) – and that a second center of health research is located in the San Francisco area of California, also features several renowned universities. This type of ecosystem attracts major world pharmaceutical companies, which in turn establish research centers in the area to gain an advantage from proximity to sources of basic knowledge.

A second important aspect is that health innovation is expensive and time-consuming, unlike sectors like software design where development costs are usually lower and new products and services enter the market constantly. The innovation process in health begins with a piece of basic research carried out in university labs and research institutions, places that house knowledge about the evolution of diseases and about the substances that can act on them. A particular piece of research may lead to the discovery of a new molecule likely to act on a particular disease or condition, for instance. After the discovery is made, the process of developing a new drug may take up to ten years, with further studies of the molecule, pre-clinical tests performed on tissues or animals, and clinical studies in humans.

One good example of the time it takes to develop such a drug is captopril, one of most widely used drugs in the world for controlling high blood pressure, and in whose development Brazilian science played an important role. One of the main components of this drug is a substance – called bradykinin – found in the venom of the *jararaca* snake, and discovered by researchers from the Ribeirão Preto Medical School at the University of São Paulo. Maurício Oscar da Rocha e Silva isolated the substance and identified its hypotensive effects in the 1940s. In the 1960s, one of Silva's former students, Sergio Ferreira, discovered another substance that increased and prolonged the hypotensive effects of bradykinin in the body, in the process also making new discoveries regarding the drug's effect on lung tissues. Ferreira examined this topic while pursuing his doctoral degree and, subsequently, working in laboratories in the United Kingdom and United States. After many years and many studies by Ferreira and others, a drug was finally developed from the compound by researchers from the United States pharmaceutical company Bristol-Myers Squibb. In 1980, the United States Food and Drug Administration (FDA) – an organization with the same purpose as the Brazilian Health Regulatory Agency (Agência Nacional de Vigilância Sanitária – Anvisa) – approved the use of the drug captopril.

According to the Tufts Center for the Study of Drug Development, the cost for producing and introducing a new drug into the market is estimated at more than \$2.7 billion, and includes a number of preclinical and clinical studies required to prove the efficacy and safety of a new drug or device to humans.[1] A different study published in November 2017 suggested a much lower estimate of just over \$600 million for the development of a new drug for cancer treatment (Prasad and Mailankody, 2017). Although the precise numbers are debatable, the fact is that producing innovation in the health field is more expensive than in most other sectors. Clinical trials have been found to represent more than half the cost of developing a new drug. And such costs have been on the rise in recent years for a couple of reasons: tests are becoming more complex; the industry is focusing more on chronic and degenerative diseases; and insurers and health plans are now carrying out comparative tests to assess the effectiveness of different drugs.[2]

A third aspect that sets health innovation apart from innovation in other sectors is the higher risk. According to the FDA, less than 6% of drugs submitted to clinical trials reach the final stage and are registered for commercial distribution.[3] This low success rate is one of the reasons behind the high costs of health research. It also has implications regarding the availability of funding

1. Research center at Tufts University, in Boston, available at: <http://csdd.tufts.edu/index.php>. See DiMasi, Grabowski, and Hansen (2016).

2. Available at: <https://www.scientificamerican.com/article/cost-to-develop-new-pharmaceutical-drug-now-exceeds-2-5b/>.

3. Available at: <https://www.fda.gov/ForPatients/Approvals/Drugs/ucm405622.htm>.

towards innovation in the sector. As we have seen, innovation involves higher capital costs than regular investments because of its high risk; in the health field this proves to be even more problematic.

Lastly, the fourth distinctive feature is that health research is a highly regulated activity, as is the health market in general. It is regulated not only because of its high importance and social impact, but also because research in this field concerns ethical issues and potential risks to patients. Thus, much health research requires authorization and approval from various government agencies. Obviously, this need for authorization makes the research process slower and more bureaucratic than in other fields. Although regulation is strongly enforced worldwide, in many countries there is an effort to connect researchers, research institutions, companies, and agencies responsible for this regulation in order to reduce the costs and the time frame required for research approval.

2 CLINICAL TRIALS

Clinical trials are the final stage of a long research and development process that begins in a university or research center lab, and then includes tests on actual human tissue and animals. Clinical trials are studies intended to assess whether a new drug, treatment, or device is effective on humans. They must also evaluate the effectiveness of alternative treatments, analyze how different groups of people react to them, and look for potential harmful effects on the human body. These trials are necessary because an approach that works well on tissues or animals does not always work well on humans.

This type of test complies with very strict safety and ethical protocols: after all, the effects of an unknown substance are being tested on actual patients. Therefore, the tests are staggered across different phases, allowing a gradual growth both in the number of patients and in the scope of the questions. The first phase begins with small groups of patients, and the dosage of the drug they receive gradually increases in order to find out if the new drug causes any unexpected health issues. Thus, the focus of the first phase is on patient safety. In later phases, the number of patients is increased, in order to define treatment and control groups (those who receive the new treatment versus those who receive the conventional treatment). It is also necessary to determine whether the treatment is appropriate for all subtypes of the target disease and for all groups of people it effects. These constitute phases II through IV of the clinical trials. The table below offers the description of each one of them.

Although this is a sensitive issue, at this time it is not yet possible to find substitutes for human subjects, nor for the animals used in preclinical stages. Recently, a research center located in Boston and linked to Harvard was able to develop microfluidic cell culture chips capable of simulating how human organs function.[4]

TABLE 1
Phases of clinical research

Phase	Number of patients	Purpose of study	Phase duration	Probability of the drug reaching the next stage (%)
I	Twenty to a hundred individuals, usually healthy	Safety and dosage	Months	70
II	Several hundred people suffering from the disease or condition	Efficacy and side effects	Up to two years	33
III	Thousands of volunteers suffering from the disease or condition	Efficacy, interaction with other drugs and adverse reactions	Up to four years	25
IV – after approval	Thousands of individuals suffering from the disease or condition	Pharmacovigilance: monitor side effects and effectiveness	Undetermined	Approved drug

Source: FDA. Available at: <https://www.fda.gov/ForPatients/Approvals/Drugs/ucm405622.htm>.

The project, called Organs-on-Chips, was funded by DARPA (yes, the Defense Advanced Research Projects Agency), and cost approximately $ 37 million. In the future, such technology is expected to replace clinical trials in patients, at least partially. But there is still a long way to go until this becomes a reality. For now, clinical trials remain critical to the development of new treatments, medications, and devices.

In addition to being indispensable to the development of new drugs and treatments for society as a whole, trials also benefit the volunteers who decide to take part in them. Generally speaking, these are individuals for whom the existing treatments have not worked, in terms of recovering from a disease or improving their condition. Therefore, taking part in a clinical trial may be their only option to receive a more effective treatment than those already available.

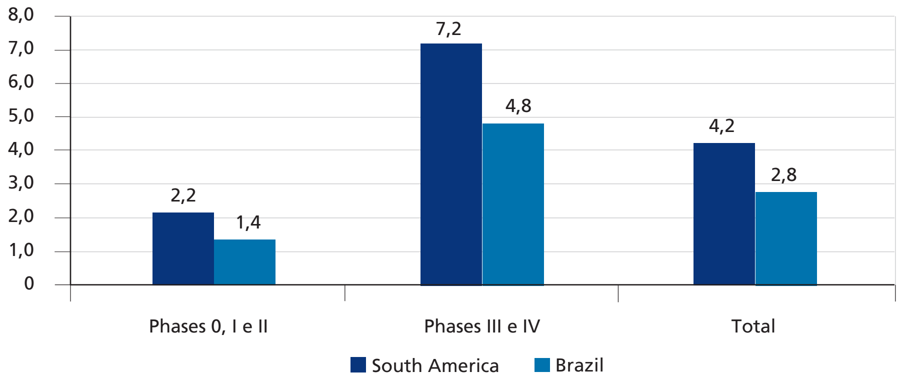
Furthermore, it is very difficult for companies and research institutions from any given country to join the global health knowledge networks without performing such clinical trials, which are an essential part of the research in the field.

Brazil does not contribute much as far as global clinical trials are concerned, registering only 3% of the more than 130,000 trials carried out in recent years.[5] The United States alone accounts for 45% of the total, followed by Canada and Germany with slightly less than 10% each. As it turns out, clinical trials are still very concentrated in the United States, especially in the early stages (phases

4. Available at: <https://wyss.harvard.edu/technology/human-organs-on-chips/>.
5. Available at: <https://bit.ly/362NNDg>.

0 to II), which represent a vast wealth of knowledge.[6] In these phases, Brazil accounts for less than 1.5% of the total, as shown in the chart. However, performs the largest number of trials in South America (Argentina accounts for less than half of Brazil's total number of clinical trials).

CHART 1
Brazilian and South American participation in clinical trials – phases 0 to IV (Jan./2000-Jan./2018)
(In %)



Source: ClinicalTrials.gov.

In recent years, given the increasing cost of performing clinical trials, large pharmaceutical companies have begun outsourcing this activity, or part of it, by hiring so-called Contract Research Organizations (CROs). CROs are companies or institutions that specialize in providing support and services clinical trials and drug safety, or even pre-clinical trials for pharmaceutical companies. The pharmaceutical company can hire these organizations for specific tasks or activities, and keep managing the development process; or even hire them to carry out all the required stages to register a product, outsourcing the entire development process (Gomes *et al.*, 2012).

The development of captopril is a good example of how important it is to take part in the conduction of clinical trials, for a country that wishes to be innovative in the health sector. Even though the active ingredient of the drug was discovered in Brazil, and by a Brazilian scientist, the drug could only be developed after a United States pharmaceutical company conducted pre-clinical and clinical trials. Joining the global clinical trial scenario also requires a good scientific infrastructure, trained personnel, and a favorable regulatory environment.

6. Phase 0 consists of exploratory studies conducted prior to the beginning of the clinical trials with a very small number of subjects and intended exclusively to determine how the new drug affects the body.

3 RESEARCH INFRASTRUCTURE

As in any other field, innovating in health requires a substantial scientific base. There is no innovation without knowledge production and this is even more prominent in sectors such as health, where innovation is highly science intensive. Health innovation begins with better understanding a disease, its causative agents, its vectors, and its effects on the human body. All of this depends heavily on basic research.

We now know the causes of innumerable diseases; but until the end of the nineteenth century we were unaware of their origin. The microbial theory of diseases became widely accepted by society and the scientific community only at the end of the nineteenth century. The discovery that many diseases were in fact caused by microorganisms was a major scientific breakthrough that allowed for the development of vaccines and specific treatments for various infectious diseases, many of which were lethal up to that time. Note that until the first quarter of the last century, diseases such as pneumonia, tuberculosis, and diarrhea were the principle causes of death, accounting for almost 30% of the mortality rate in the United States.[7] In the early 1900s, infectious diseases killed between 700 and 800 of every 100,000 people each year. People died of infected wounds, something virtually unthinkable nowadays. Antibiotics were the main reason for the drop in mortality from this type of disease, which currently kills less than fifty in every 100,000 inhabitants. The production of antibiotics only began in the 1940s, after scientist Alexander Fleming discovered in 1928 that penicillin prevented the reproduction of strains of bacteria that caused numerous diseases. In other words, only after the discovery of bacteria could humans develop antibiotics. The 1983 discovery that HIV is the virus that causes AIDS is another example of a scientific breakthrough that paved the way for the development of drugs that ultimately allowed us to control the disease.

Basic scientific research is therefore essential for technological advancement in the health field. In recent years, however, there has been growing awareness that science seems to be advancing faster than the ability of the industry and regulatory agencies to convert this new knowledge into new treatments and drugs that could benefit the entire society. As a result, one of the trends in this area is known as translational research. Translational medicine is a rapidly growing multidisciplinary field in biomedical research, whose goal is to accelerate the discovery of new treatments and new diagnoses based on existing research results at universities and research centers.

7. Available at: <https://www.cdc.gov/Mmwr/preview/mmwrhtml/mm4829a1.htm>.

The logic that guides translational research is the idea that many findings in basic research that have not yet been applied to clinical trials, and that many positively-evaluated protocols have not yet become standard clinical practice. That is, there is a huge gap in biomedical research linked to the application of available knowledge produced in universities and research centers. According to National Institutes of Health (NIH),[8] "the current drug development pipeline has significant bottlenecks, and the movement of basic research into clinical use is slower than desired."

This observation has led to the adoption of research strategies aimed at making the most of available knowledge, and at speeding up the trials of newly discovered drugs and treatments. For this reason, in 2012 the NIH built a new research center, the National Center for Advancing Translational Science (NCATS), to help remove obstacles hindering the transition from basic research to development, thus accelerating the delivery of new drugs, diagnostics and medical devices to patients.[9] NCATS had an initial budget of over $ 570,000, and its annual budget for fiscal year 2016 was nearly $ 700,000.

This trend has also been seen in business strategies. Several researchers contacted during the production of this piece of work reported that while the amount of resources available for basic research has diminished, resources have increased for the final stages of the research pipeline. At the same time, pharmaceutical companies now usually set up venture capital funds to invest in innovative ideas (new drugs or treatments) from researchers. These funds help accelerate trials and the market launch of new drugs and treatments and, from a business perspective, are less expensive than investing in basic research.

Brazil has a good scientific base in this field and an internationally-significant production level. In practically all areas of research directly related to health, Brazilian participation in global production is higher than the average. This means that, from a different perspective, these areas of knowledge are more meaningful to Brazilian scientific production than they are in the rest of the world and, therefore, Brazil is an important player. In terms of international trade, these revealed comparative advantages indicate the fields in which the country has the potential to specialize.

The areas of knowledge related to health innovation represent, in all, about 54% of Brazilian scientific production; in the world, that percentage is 40. In some fields, such as dentistry, Brazil accounts for more than 16% of the entire

8. Available at: <https://officeofbudget.od.nih.gov/pdfs/FY15/FY2015_Overview.pdf>.
9. Available at: <https://ncats.nih.gov/about/center>.

global scientific production (table 2). Some authors have pointed out that this Brazilian advantage in the field has even grown in recent years.

Obviously, this is only possible because the country has several leading institutions and does cutting-edge research in this field. Oswaldo Cruz Foundation (Fundação Oswaldo Cruz – Fiocruz), linked to the Brazilian Ministry of Health, is one of the largest research institutions in the country, and besides producing research, it also specializes in the production of vaccines and drugs. The Butantan Institute is another example of a prestigious institution, which, in addition to research, is responsible for producing vaccines. The Adolfo Luz Institute, the Biological Institute, the Heart Institute (Instituto do Coração – INCOR), and the National Cancer Institute (Instituto Nacional de Câncer – INCA) are other Brazilian institutions performing significant scientific activities. Among them, INCA has outstanding performance in clinical research.

TABLE 2
Participation in scientific areas related to health in Brazilian and worldwide publications (2012)
(In %)

Field	Participation by field in Brazilian publications	Participation by the field in world publications	Comparative advantages?	Brazil's participation in the world
Biological and agrarian sciences	15.6	5.9	Yes	6.7
Biochemistry, genetics and molecular biology	7.6	8.5	Yes	2.2
Dentistry	2.3	0.3	Yes	16.4
Immunology and microbiology	3.5	2.3	Yes	3.9
Medicine	19.4	18.7	Yes	2.6
Neuroscience	1.6	1.4	Yes	2.9
Nursing	1.6	0.8	Yes	4.7
Pharmacology, toxicology and pharmaceutics	2.5	2.2	Yes	2.8
Total	**54.1**	**40.1**	**Yes**	**1.8**

Source: Ministry of Science, Technology and Innovation (Ministério da Ciência, Tecnologia e Inovações – MTIC). Available at: <https://bit.ly/3qHexCx>.

Despite having high-level institutions in health-related fields, as well as in others, the fragmentation of research infrastructure is a reality in Brazil. In addition, there are some specific health obstacles. Researchers and entrepreneurs in the field warn, for example, that the country does not have adequate infrastructure to conduct pre-clinical research and lacks proper training for performing toxicological tests.

One infrastructural gap concerns a lack of state-of-the art animal facilities, known as vivaria. Facilities for breeding are especially scarce.[10] Only a few of the existing laboratories possess adequate infrastructure and human resources, plus the sanitary barriers required to raise animals with the characteristics desirable for new drug testing. There are no *vivaria* in the country for breeding transgenic animals. Several recent studies have pointed to the need to establish a more modern vivarium network compatible with that of several leading research institutes in the world.[11] In 2003, the Center for Management and Strategic Studies estimated that investments of less than $ 18 million (R$ 60 million) would be necessary to provide this type of infrastructure, a relatively modest investment for the size and relevance of Brazilian science in the field. A lack of laboratories capable of analyzing high-risk infectious agents in accordance with stringent biological safety protocols also represents a bottleneck in Brazilian health research infrastructure.

4 ENVIRONMENT AND REGULATION

As in any other sector, in addition to scientific production and infrastructure, it is important to provide a stimulating environment for the innovation process. In health, several of the intrinsic specificities of its innovation process are related to even greater challenges in providing such environment, and in regulating it.

The high cost of health research, coupled with the high risk of the activity, deepen the financial challenges that are characteristic of innovation in general. Worldwide, a substantial part of research in the field is funded by public resources, especially basic research conducted at universities and research institutions, and the early stages of the development of new drugs, treatments, or medical devices. As we progress in the development cycle of a new product, other important players for funding this activity begin to emerge. Venture capital funds are more common for preclinical trials and the early phases of clinical trials. More advanced clinical trials involve more people and are more expensive, thus are often sponsored by large pharmaceutical companies.

Here again, the United States is a good example of the importance of public investment in health innovation production. In the United States, the Department of Health and Human Services (HHS) accounts for about 23% of the federal government's total investments in research and development (R&D) (more than $30 billion, according to data from 2015). In addition, research investments in the field are also made by other agencies and public institutions, such as those linked to the Department of Defense. The NIH are institutions linked to the Department of Health and are the main implementers of United States scientific

10. Available at: <https://super.abril.com.br/ciencia/bioterios-quatro-e-cinco-estrelas/>.
11. See, for instance, Politi et al. (2009).

policy in the field. The NIH comprises twenty-seven institutes focused on very specific research agendas, always related to some disease or to parts and systems of the human body. The NIH has its own research infrastructure on its 300-acre campus featuring seventy-five buildings in Bethesda, Maryland, where 6,000 researchers work (De Negri and Squeff, 2014b). Yet the NIH budget for 2015 revealed that only 17% of its total investment is intended for research carried out within its buildings. The remaining 83% is destined for outside researchers through grants, cooperation agreements, and R&D contracts. This fact highlights the firm identity of the NIH as an institution that promotes research, being one of the largest funders of biomedical research in the world. According to the NIH website, its institutes have supported more than 300,000 researchers.

TABLE 3
NIH budget according to how the investment is made (2014)

Mechanism	$	%
Research grant	20,738	69
Training	738	2
R&D contracts	2.990	10
Intramural research	3,374	11
Other (management, support, facilities construction and maintenance)	2,179	7
NIH total	**30,019**	**100**

Source: NIH. Available at: <http://officeofbudget.od.nih.gov/spending_hist.html>.

Private players also take an active role in funding research in the area. In the United States, these players range from large pharmaceutical companies to private foundations and American millionaires interested in health research.[12] Pharmaceutical companies invest more than $46 billion a year in R&D in the country – that is, slightly more than the total public investment in the field.[13] Such investments go straight to these companies' R&D centers, often either by contracting researchers at North American universities or through investing in start-up companies.

One of the most prominent private foundations fostering health research in the United States is the Howard Hughes Medical Institute (HHMI), which invests approximately $800 million a year in health research and education. By 2015, the institute invested more than $660 million in biomedical research, and more than $80 million in science education.

12. Doctor Patrick Soon-Shiong, a scientist and entrepreneur who has launched his own research to seek the cure of cancer (The Cancer MoonShot 2020), is a good example of this phenomenon.

13. Data available at Science and Engineering Indicators 201 at: <http://www.nsf.gov/statistics/2016/nsb20161/>. Accessed in: Sept. 2016.

In Brazil, public investments in health research are made mainly by Fiocruz, or through the sectoral funds. Unlike the NIH, Fiocruz does not have mechanisms to fund research outside its facilities, so it only carries out research activities directly in its laboratories. Fiocruz is also responsible for the production of drugs and vaccines for the Brazilian public health system, called Unified Health System (Sistema Único de Saúde – SUS). The sectoral funds are another source of funding for health research in Brazil, as we have seen, but they have experienced significant budget cuts in recent years.

Besides Fiocruz, the Brazilian Ministry of Health does not have consolidated research investment programs in place. In recent years, the ministry's main program for science and technology was called the Productive Development Partnerships (PDPs). PDPs were more an industrial policy linked to the purchase of drugs by the public health system, than an actual policy aimed at the scientific and technological development of the sector. Although some of the partnerships included mechanisms for technology transfer from major pharmaceutical companies to domestic laboratories, their focus was the production of drugs for the Brazilian health system. In fact, the primary goal of the PDPs was to improve the government's purchasing power in order to expand the population's access to strategic products, and to reduce health system vulnerability (Varrichio, 2017). Technological development was a secondary goal. Another controversial aspect of the PDPs was the emphasis on the production of drugs by public laboratories, as if they could replace the role of private companies in manufacturing medicine. For pharmaceutical companies however, participation in PDPs was a key, indeed the only key, to access the main market for drugs in the country: SUS.

Another significant source of funding for health research comes from seed and venture capital funds. Around the world, they are the primary agents for funding research at a certain stage, once it has passed university laboratory tests but prior to the final stages of clinical trials. Although some studies revealed the recent growth of this market in Brazil, it is still underdeveloped. An example of a new player in this market is Biozeus, founded in 2012, which invests in preliminary-stage ideas from universities and research institutions, aiming to translate these ideas into marketable products (Reynolds, Zylberberg, and Del Campo, 2016). Nonetheless, there is a long road ahead to fully develop this market in Brazil, especially the need for developing exit alternatives for risk investors.

From the financial perspective, Brazil faces many bottlenecks. Despite our proven scientific capabilities, the transition from such skills into new drugs, treatments and devices requires overcoming certain obstacles. Only then will the country be able to build a sound funding strategy involving public and private players at all stages of product development.

Another characteristic of the sector that results in significant bottlenecks concerns the fact that health research is a highly regulated activity. Thus, an efficient regulatory process is crucial to the development of research. In particular, when it comes to clinical trials in humans, regulation is critical to ensure adherence to correct protocols and ethical standards in research. However, regulation also requires agility so as not to hinder Brazilian participation in ongoing research, often carried out through international partnerships.

As for regulation, one of the issues pointed out by scholars and experts in the field concerns the timeframe Anvisa takes to approve clinical trials. A recent Banco Nacional de Desenvolvimento Econômico e Social (BNDES) study on the topic shows that timeframe for the approval of clinical trials in Brazil tends to take longer than the international average, a fact also corroborated by other studies on the subject (Gomes, *et al.*, 2012). Experts in the industry warn that sometimes this delay prevents Brazil from participating in simultaneous studies conducted in several countries.

One of the reasons behind this delay in the approval process is the existence of several stages of approval. The first step is to receive approve from the research institution's ethics board. Although legislation sets a maximum period of thirty days for the board's decision, as these institutions are autonomous, this period may be extended. In some special cases, in addition to the approval from the ethics board, the process needs to be reviewed by the Brazilian National Council of Research Ethics (Comissão Nacional de Ética em Pesquisa – CONEP), which may take up to six months (Gomes *et al.*, 2012).

Besides the ethics board/CONEP system, clinical trials in Brazil have to abide by a series of regulatory standards issued by Anvisa and the National Health Council (Conselho Nacional de Saúde – CNS). One piece of legislation currently before the Federal Chamber of Deputies, bill 7082/2017 (drafted in the Senate as PLS 200/2015), would establish standards regarding clinical research in humans and create a national code of ethics in research. This presents a good opportunity to enhance and consolidate all regulations for clinical research, which are currently dispersed across various resolutions.

Another aspect that limits Brazilian participation in clinical research worldwide is cost. Recent studies suggest that the long delays and the high cost of clinical research in Brazil prevents clinical trials from being carried out there, an issue confirmed in conversations with businessmen based the Boston area.[14] Some companies point to Brazil's requirement for the mandatory furnishing of drugs to clinical trial subjects after the study is concluded as one of the factors that

14. See, for instance, Reynolds, Zylberberg, and Del Campo (2016).

make these tests in the country more expensive. This is all the more significant for research on drugs for rare diseases, or those whose total quantity of patients is not large.

Finally, it is important to emphasize that Instituto Nacional da Propriedade Industrial (INPI) is a major bottleneck for innovation in the sector. In the pharmaceutical field, more than in any other sector, what ensures innovators a return on their entrepreneurship is the granting of a patent. In a country where filing a patent can take up to eleven years, innovation in this sector ends up seriously undermined.

CHAPTER 7

NEW PATHWAYS FOR SCIENCE AND TECHNOLOGY POLICIES[1]

1 INTRODUCTION

As we have seen throughout this work, there are many obstacles preventing Brazil from becoming a more innovative country. These obstacles range from the training of scientists and researchers to the strengthening of the infrastructure necessary for the full development of its activities, including an economic environment more conducive to innovation. All or most of these aspects can be influenced or improved through the implementation of appropriate, sensible public policies.

These policies should not seek to force companies to innovate, as this would be meaningless; nor should they tell scientists what they should research, since policy makers and bureaucrats do not have the expertise to make such decisions. They must, therefore, rely on scientists to indicate the scientific paths and on companies to forge innovative paths.

However, policies must also take into account that there are important market failures, and therefore market mechanisms and incentives will not be sufficient to secure the necessary investments in science and technology. Policies also can and should rely on scientific knowledge and technological progress to address critical issues affecting the country's development. Using science to solve public health issues, infrastructure, connectivity, and other issues should be one of the objectives of science and technology (S&T) policy.

Thus, in addition to affecting the other factors, public policies must themselves be rethought and updated in light of empirical evidence on their results and the results of international experiences. Well-informed, evidence-based public policies are crucial to achieving goals. Unfortunately, Brazil has not been a good example in terms of formulating policies based on sound technical knowledge. Respect for science and knowledge is expressed not only through support for S&T, but also by the use of expert knowledge for formulating policies.

1. Many of these proposals have already been presented at other times in documents published by Ipea, such as De Negri (2015), De Negri (2017) and De Negri, Rauen, and Squeff (2017).

This is why planning is needed. A first step in this direction is to prepare long-term plans for the area – some kind of ten-year S&T plan, with long-term priorities and guidelines, not just a patchwork of private demands. This plan must also express a consistent view of what the country expects from its science and technology and the mechanisms to achieve those objectives.

Brazil will only be a richer and more productive country to the extent that it is able to use scientific and technological knowledge as the driving force behind its development and to the extent that it understands that this is the only possible path forward. For this to happen, we must build consensus and augment collaboration. The idea that science and technology are essential for development must be disseminated throughout society, business, and the public.

2 STRENGTHENING SCIENCE AND UNIVERSITIES

There is no innovation without knowledge. So, the first step towards making the country more innovative is to focus on building skills, building human capital, and strengthening the infrastructure needed to do so. This involves strengthening and boosting the country's universities and research institutions. There is no point in improving the economic environment for innovation if the essential raw material for this – knowledge – is not being produced in Brazil.

2.1 Expansion and enhancement of investments in research infrastructure

Quality scientific production requires well-trained scientists and adequate laboratory infrastructure. As we have seen, the scientific research infrastructure in Brazil, with rare exceptions, is composed of small laboratories scattered throughout the departments of Brazilian universities. Large infrastructure, such as Sirius at National Research Center for Energy and Materials (Centro Nacional de Pesquisa em Energia e Materiais – CNPEM), or the Integration and Testing Laboratory at National Institute of Space Research (Instituto Nacional de Pesquisas Espaciais – INPE), are relatively scarce.

Some research fields require large-scale, multi-user facilities open to researchers from all over the country and abroad. The construction of this type of facility, however, requires large investments for several years in a row. Thus, planning and prioritization are needed.

This type of long-term planning requires that the scientific community takes a position on what the long-term priorities should be, and which investments would benefit Brazilian science the most. The business sector should also participate in this effort in order to determine which areas would have the greatest impact on the competitiveness of the country. The Ministry of Science, Technology and Innovation (Ministério da Ciência, Tecnologia e Inovações – MCTI) should be a catalyzing agent in terms of developing the skills and knowledge available in Brazil, and knowing what would be Brazil's most urgent needs in terms of research infrastructure.

Some guidelines for the area, based on best practices from abroad, would be the following.

2.1.1 Develop long-term planning for investment in research infrastructure

Brazil must develop, together with the Brazilian scientific community, a roadmap and long-term planning for investment in research infrastructure in Brazil. This planning could be conducted by MCTIC or Center for Management and Strategic Studies (Centro de Gestão e Estudos Estratégicos – CGEE), and one model to follow could be that of the European Research Forum on Research Infrastructures (ESFRI), which proposes a roadmap for selecting research infrastructure projects capable of leveraging European competitiveness in the long run.[2] The Australian experience could also serve as a model. What is essential is that this planning reflects a collaboration between the government, scientists and, where relevant, companies in order to ensure stability and predictability for these investments and to choose the best alternatives.

2.1.2 Invest in the creation of open, multi-user infrastructure with efficient management

Investment in infrastructure should prioritize the creation of large multi-user laboratories capable of supporting the production of world-class science. These institutions could be non-profit organizations or public/private partnerships capable of flexibility and operational agility, especially with regard to the hiring of personnel and services and the purchase of materials.

2.1.3 Encourage the transformation of some existing laboratories into multi-user laboratories

It is possible simultaneously to promote the conversion of existing, large-scale laboratories into open, multi-user facilities, in which there are clear rules and transparency regarding the use of equipment. This type of infrastructure could be facilitation through providing specific assistance or grant programs for laboratories that become multi-user.

2.1.4 Reformulation of Infrastructure Sectoral Fund (Fundo Setorial de Infraestrutura – CT-Infra)

The main support fund for investments in infrastructure in Brazil is CT-Infra, one of the Fundo Nacional de Desenvolvimento Científico e Tecnológico (FNDCT) Sectoral Funds. This fund has depended heavily on oil royalties. It is therefore

2. Available at: <https://ec.europa.eu/research/infrastructures/index_en.cfm?pg=esfri>.

necessary to reconstitute and expand the amount of resources available in this fund so that the other guidelines suggested above can be implemented. The fund's operation model also needs to be revised in order to allow for larger investments and to ensure monitoring and evaluation of the results of these investments. Currently, the fund operates through public calls for proposals, wherein universities submit a variety of small investment projects under an institutional umbrella.

2.2 Stimulate internationalization and diversity in Brazilian science

We have already seen that being part of international knowledge networks is crucial to the quality of the science produced in a country, and that Brazilian universities are still not very internationalized. There are several hurdles currently preventing greater internationalization. First, although it is entirely possible (and there are no legal impediments), few Brazilian universities that conduct hiring procedures in a language other than Portuguese. One that does, the Federal Fluminense University, created regulations in 2016 for foreign-language hiring procedures and started offering courses in other languages. However, the new regulations also dictate that approval of employment past the trial period, on which depends the career of the newly hired professor, will be based on his or her proficiency in Portuguese.[3]

If universities and research institutions in Brazil truly want greater internationalization, deeper changes to our S&T system are needed. There is some progress in this direction, such as the mid-2016 decree that facilitates the validation process for foreign diplomas and the announcement by the president of Coordination for Improvement of Higher Education Personnel (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES) that it would open a specific call for proposals related to the internationalization of Brazilian universities.[4] The following suggestions also lead in that direction.

2.2.1 Further facilitate the recognition process for foreign diplomas by establishing an automatic process for high-quality courses and institutions

The lag in recognition of diplomas obtained from educational institutions outside of Brazil is a significant bottleneck preventing the greater internationalization of Brazilian science. Currently, the recognition process is done by Brazilian public universities accredited by the Ministry of Education and Culture (MEC) or by private universities, in the case of graduate diplomas. Recently, the MEC established new procedures for this recognition that simplified the process and set the maximum deadline of 180 days for recognition by Brazilian

3. Available at: <http://www.uff.br/sites/default/files/news/arquivos/res_cepex_447_2015_concurso_idioma_estrangeiro_bs_161-2015.pdf>.

4. Available at: <http://portal.sbpcnet.org.br/noticias/presidente-da-capes-anuncia-edital-para-internacionalizacao-de-universidades-brasileiras/>.

universities.[5] To facilitate this, MEC created a platform (Carolina Bori) through which students can request revalidation of their diplomas online, select the institution that will carry out the analysis, attach the necessary documents and monitor the process. Although this was a major breakthrough, the process could improve even more with the development of an automatic procedure for recognizing courses at leading institutions.[6] One inspiring model that is being adopted in the European Union is called FAIR: Focus on Automatic Institutional Recognition.[7] In this model, consolidated courses at some foreign universities would be included in an automatic recognition process.

2.2.2 Encourage universities to provide courses, especially graduate courses, in a foreign language

Brazilian universities will not really internationalize if they teach courses only in Portuguese. Again, there is nothing in existing legislation that prevents these institutions from teaching courses in other languages. At the undergraduate level, there could still be resistance due to the possible restriction in access that courses taught in foreign languages may represent for students who did not have the opportunity to learn other languages previously. However, it is necessary to encourage universities to teach at least some courses, especially graduate courses, in languages other than Portuguese with foreign professors. The government can promote this type of approach on the part of universities by granting more grants and scholarships for graduate programs taught in a foreign language, for example.

2.2.3 Establish incentives for hiring foreign teachers and researchers

It is important to incentivize open and competitive hiring processes at universities and at scientific and technological institutions, in Portuguese as well as in English. As part of the process of opening up and connecting with the world, public hiring processes associated with the Brazilian S&T system should allow the genuine participation of foreign scientists. Carrying out an international search for talent to work in Brazilian universities should be routine, not an exception (as it currently is).

2.2.4 Facilitate approval of work visas for foreigners, especially for highly qualified professionals

Brazil must ensure that, in addition to the researchers themselves, professionals in other fields have easier access to Brazil. Professional councils need to be internationalized or have their influence circumscribed. A more immediate measure is to facilitate the approval of work visas for highly skilled workers.

5. Available at: <http://www.capes.gov.br/sala-de-imprensa/noticias/8196-novas-regras-vao-facilitar-a-validacao-de-diplomas-emitidos-por-instituicoes-do-exterior>.

6. Available at: <http://dapp.fgv.br/revalidacao-e-reconhecimento-de-diplomas-no-brasil-uma-via-crucis-perto-fim/>.

7. Available at: <https://www.iau-aiu.net/NUFFIC-FAIR-Report>.

2.2.5 Gradually expand the number of scholarships for graduate students and Brazilian researchers in leading institutions abroad

The Science without Borders Program was poorly formulated and executed, but it cannot be denied that the reasoning behind the program was correct: Brazilian science must be internationalized, and this internationalization is largely the result of the connections of researchers who spend part of their career working and researching abroad. Thus, increasing the number of Brazilian students in international institutions is crucial to expanding the internationalization of Brazilian science.

2.2.6 Promote programs to encourage diversity in universities and penalize excessive academic inbreeding

2.3 Promote the differentiation and specialization of institutions and academic excellence

Compared to other countries, Brazilian universities and research institutions are fairly homogeneous. Universities, especially public universities, are not encouraged to specialize in their areas of greatest expertise or in the activities where they display the most strength. All of them develop a huge range of activities, including professional training, extension courses, scientific research, academic training, health-care services in university hospitals, technical education, and distance education. Yet this is done at the expense of the quality of these activities. It is unreasonable to expect all Brazilian universities to excel in all these activities and in all areas of knowledge. We must promote the differentiation and specialization of universities.

In addition, unlike other countries where a substantial part of scientific research is done outside universities, there are few research-oriented institutions in Brazil and, for the most part, those that do exist are public institutions. Private, non-profit institutions that receive public financing have proven to be a much more efficient and flexible model for cutting-edge scientific research worldwide. In Brazil, there are the organizations linked to MCTIC that approximate this model. There are only six such institutions, but several are of recognized academic excellence and provide invaluable public services to the country, including the Institute of Pure and Applied Mathematics (Instituto de Matemática Pura e Aplicada – IMPA) and the CNPEM. We should bet on the differentiation of Brazilian institutions, on other forms of public-private partnerships, and on new models of governance and management.

2.3.1 Create a program to promote academic excellence, with additional resources for universities

Brazil must define transparent criteria for institutional assessment and link them to the provision of additional resources to public education and research institutions, with the objective of rewarding institutions of excellence. In most universities and research institutions around the world, a portion of revenue is derived from competitive sources of funding, based on projects or linked to specific performance criteria. Maintaining the current base funding levels of universities, which would guarantee their operation, a fund could be created with additional resources that would be distributed based on strict academic excellence criteria. These criteria could include, for example, the degree of internationalization of universities, the impact of their research, and the degree of diversity (and, conversely, the degree of insularity), among others. International models that could be used as inspiration include the funding model of English universities, known as the dual support system, in which a part of university funding is budgeted and guaranteed, and another part is dependent on academic performance criteria.[8] Germany, whose universities are not among the best in the world, recently created a program of academic excellence to improve their reputation. The program is called the Excellence Initiative and aims to improve the quality of German universities and research institutions.[9]

2.3.2 Strengthen and expand public-private models of scientific and technological research and strengthen the social organizations model

Brazil must strengthen and consolidate different models, such as the social organizations (*organizações sociais*), which are examples of successful models in Brazilian S&T. These non-profit organizations were inspired by the United States. National laboratories and, since they have a special legal nature, they are much more agile than purely public research institutions. It is necessary to consolidate this model, ensuring transparency in the governance and use of resources and maintaining the flexibility of their management, without excessive bureaucracy, as has been the case. In order to achieve this, a closer dialogue with governing bodies is necessary in order to create transparent mechanisms that do not result in excessive institutional rigidity. In addition, stimulating the exchange of researchers and professors between public institutions and other national public institutions, private companies, and/or international institutions may foster higher quality research. Scientists need to be encouraged to circulate among institutions with different cultures, natures, and management models.

8. This model was described in Squeff and De Negri (2016).
9. Available at: <http://www.dfg.de/en/research_funding/programmes/excellence_initiative/index.html>.

2.3.3 Create new institutions and research centers, with specific missions

Brazil must invest in the creation of new institutions and research centers with specific missions, such as researching certain diseases or alternative sources of energy, among other possibilities. A recent good example was the creation of the National Bioethanol Science and Technology Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE). These institutions should have sufficient scale to be cutting-edge at the global level and to allow the emergence of other specialized laboratories to provide scientific services (tests, analyses) to researchers, generating gains in scale and greater efficiency in scientific production. The Core Facilities, supported by the National Institutes of Health, in the United States, are an example of this type of infrastructure. They are shared laboratories that provide access to instruments, technologies, and services (including expert consultations) to researchers for a fee, which is used to maintain the laboratory.

2.3.4 Enable universities and public research institutions to create non-profit organizations to manage their main laboratories

This type of arrangement would mean greater flexibility in the operation and management of research by universities and public research institutions: for example, the purchase of material and equipment for research, or hiring temporary researchers. The objective would be to make these institutions more agile and competitive in order to carry out cutting-edge research.

2.3.5 Reduce bureaucracy and standardize legal understanding of the basic procedures for the operation of universities and research institutions

One of the great sources of useless bureaucratic procedures within Brazilian universities and public institutions is the lack of knowledge among their managers about pertinent legislation. Even the members of the Office of the General Counsel for the Federal Government (Advocacia-Geral da União – AGU) – responsible for legal opinions on basic institutional processes – have different understandings of the same issues. Conflicting legal opinions between the institutions or, sometimes within the institution itself, are evidence of this problem. Uncertainty and lack of knowledge of legislation leads managers to protect themselves by adopting redundant and ineffective procedures.

Training managers of research institutions and lawyers working in these institutions, as well as the preparation of guidelines by the AGU and the government, could mitigate these problems.

Training professionals in oversight agencies to work specifically on S&T issues, and keeping them focused on S&T issues for a long period of time, could also be a solution. Currently, these professionals migrate among various government agencies and it is not uncommon for them to completely change their area of expertise. A lawyer familiar with major infrastructure projects, for example, will find it more difficult to become familiar with S&T legislation and its special features. This training effort and a certain stability among the S&T professionals in the oversight agencies could open up dialogue between these entities and research institutions to seek solutions to the bureaucratic problems that hamper scientific research in Brazil.

2.4 Create alternative sources of revenue for universities and research institutions

The fiscal crisis faced by Brazilian states, the federal government, and a number of renowned universities has sparked a debate over university funding and scientific research in Brazil. The debate is welcome, as is the suggestion of alternatives to boost professional training and the production of knowledge in Brazil.

In fact, a survey on several leading universities around the world, including public institutions, highlighted a greater diversification of sources of funding, as we have already seen. These sources include donations, equity funds, tuition, and research revenues. Despite the government being the main funder of scientific research, other sources of revenues could help maintain the needed level of funding for universities and research institutions.

2.4.1 Enable and encourage universities and public research institutions to create endowment funds

Endowment funds are very important at United States universities, especially private nonprofit universities. As we have seen, in public universities they account for a smaller portion of revenues: only 5%. As this kind of donation is not traditional in Brazil, the relevance of such funds in terms of university finances is usually even lower. Although donations will not solve all issues with university funding, it is essential to leave this option open, because it may become more relevant in the future.

According to the managers of existing endowment funds, more trust must be given to donors, which would be attained by authorizing institutions to create their own legal frameworks for endowments.[10] There is currently a bill concerning this issue (Bill nº 4,643/2012) before the Brazilian Congress. Congress should accelerate its progress and also extend its scope to include private nonprofit universities, state universities, and research institutions, since the project currently provides this possibility only for federal higher education institutions.

10. Available at: <https://economia.estadao.com.br/noticias/geral,fundos-de-doacoes-avancam-no-pais-imp-,1524740>.

2.4.2 Provide tax incentives for companies and individuals that donate to universities and research institutions

The government should permit individuals or companies who donate to universities and research institutions to benefit from tax incentives. This involves changes in legislation that enable institutions (public or private) to make sure these funds are under professional management, in addition to tax incentives that encourage private donations to S&T. In the long term, this kind of fund could represent a relevant source of funding for universities and other research institutions. The United States model for tax incentives regarding this type of donation could be a good source of inspiration. Brazil already has a comparable incentive for cultural activities: the Rouanet Law. Why not do something similar for science (while avoiding the potential for misunderstanding contained in that law)?

Tax incentives, such as an exemption for the donation tax when donating to scientific research, could also be used to stimulate the creation of private institutions supporting and fostering science, as the newly established Instituto Serrapilheira demonstrates.

2.4.3 Extending the inheritance tax, and creating deductions for it linked to donations to R&T

In Brazil, the inheritance tax rate ranges from 6% to 8%, depending on the state. In the United States, the corresponding rate is 40%, and in some European countries it is higher than 60%. There is ample scope for extending this tax in Brazil, which could then be reduced by some fraction were some of that wealth donated to S&T institutions.

3 IMPROVING THE INSTITUTIONAL AND SYSTEMIC CONDITIONS FOR INNOVATION

Cutting-edge knowledge produced in universities and research institutions cannot be converted into innovation if companies at the other end of the system do not have the right incentives to innovate. Companies are the agents that will convert academic knowledge into new products and processes to be introduced into the market.

Building an economic environment in which capital costs are smaller, more dynamic, more competitive, and less bureaucratic is therefore essential for a fully functioning national innovation system.

3.1 Promoting greater level of integration into global value chains: more openness, more competition and more access to technologies

The Brazilian economy has spent too long being too closed. This, coupled with an outdated view of the need to build entire supply chains inside the country, has cut us off from participating in global networks for the production of goods and technologies. Unfortunately, Brazil and Mercosur have missed many opportunities to widen their economies in more conducive international circumstances than the current one. Now, in the midst of a worldwide movement in reaction to globalization and a global protectionist wave, once again Brazilian protectionist forces seem inclined to oppose any opening movement.

Despite this complex scenario, Brazilians must be aware that we have been the real losers from our excessively closed economy. It is our industry that does not have access to the current world supply of capital. And it is our industry that cannot embark on the process of adapting to the so-called Industry 4.0, thanks to a lack of access to foreign technology. This is why we must move towards becoming more open to international trade, gradually and with transparency.

3.1.1 Set out a timetable for gradually opening the economy with the goal of achieving import tariffs close to the world average within a decade

The major error committed in the process of opening up, implemented by the Collor administration, was perhaps its pace. The processes of tariff reduction should be gradual and coupled with improved economic conditions, so that companies can little by little gain competitiveness and prepare to face a higher level of competition. It is also important to start with sectors where the positive impacts resulting from opening up (efficiency gains due to access to new technologies incorporated in consumer goods and/or cheaper imported inputs) would be higher. For this kind of planning to be convincing and to survive government transitions, it must be turned into a social agenda. Therefore, we must build a consensus around these ideas.

3.1.2 Assess and review local content policies and margins of preference

In the last few years, these policies were applied indiscriminately across the country, with results that were dubious at best. We must avoid the use of margins of preference in public purchases and effectively restrict local content policies, prioritizing products with high-tech content and based on careful technical evaluations, on forecasts and on results.

Margins of preference policies give advantages (generally price advantages) to certain groups of suppliers (usually local ones) in public procurement processes. In Brazil, this type of policy was adopted in 2010 and enabled the government to pay up to 20% more for products manufactured in Brazil than for imported goods. In the case of products manufactured with technology developed in Brazil, this margin could reach 25%. But the difficulty in regulating what was considered technological development in Brazil has meant that, in practice, no technologies – with the exception of certain information and communication technologies already covered by specific legislation – could benefit from the policy.[11]

3.1.3 Creating mechanisms to facilitate the imports of research inputs and equipment

Brazil must create agile, differentiated, and low-cost mechanisms (reducing tariffs, when necessary) for importing inputs, reagents, research equipment and related services, and prototypes. The Program Importa Fácil (meaning, easy imports) is a first step, but so far has failed to reduce the bureaucracy associated with importing research inputs.

It is reasonable to assume that, to the extent that the economy is opened, imports of this kind of product also tend to be facilitated. However, the country cannot wait this long. An alternative could be the creation of a credit rating for researchers, research and development (R&D) companies, and institutions, in order to speed up the import process for those professionals previously qualified to operate. Another possibility is to concentrate the flow of imports at a specific airport, which would function as a hub where agents of the Federal Revenue Service, Customs, Brazilian Health Regulatory Agency (Agência Nacional de Vigilância Sanitária – Anvisa), and others agencies would receive special training to speed up the entrance process for this type of cargo.

3.2 Reducing the cost of capital for investments in innovation

The cost of capital is a significant bottleneck for the Brazilian economy as a whole, not just for innovation. The country's interest rate reduction agenda is complex and involves several fronts. At the forefront is addressing the issue of public debt, fighting against inflation, and the resulting reduction in the base interest rate. This agenda also includes increased competition in the credit market – which could stimulate the reduction of financial spreading – coupled with greater transparency in credit information brought by initiatives such as the credit rating, currently being considered by the congress.

When it comes to innovation, there are also additional market failures that drive the cost of capital even higher. Therefore, designing public policies aimed at reducing the cost of capital is essential.

11. The first chapter of Rauen (2017) presents a good assessment of this policy weakness, including the hurdle to actually evaluate its results.

3.2.1 Evaluate and reinforce fiscal incentive policies for R&D, such as the Lei do Bem (the Law for the Good)

Creating tax incentives for investments in R&D is an alternative to reduce the cost of capital associated with innovation. The Lei do Bem, adopted in Brazil in 2006, allows companies to deduct up to twice the value of their R&D investment from their income subject to income tax. The evidence available to date indicates that this law has had a positive effect on R&D investment by Brazilian companies. Without doubt, among all the fiscal incentives aimed at encouraging innovation in Brazil, this has been the most effective.

3.2.2 Extend credit lines for innovation to Banco Nacional de Desenvolvimento Econômico e Social (BNDES) and Financiadora de Estudos e Projetos (FINEP)

Historically, credit has not been the main mechanism for funding investment in innovation, although in recent years the use of credit for this type of investment has expanded. Obviously, credit will not be used for disruptive innovations or startups (this kind of innovation requires other sources of funding). However, incremental innovations (which are the vast majority of innovations) and the costs associated with the introduction of innovations in the market can be stimulated through credit mechanisms.

3.2.3 Improve regulation in order to stimulate the Brazil's venture capital market

Venture capital is one of the main funding mechanisms for disruptive technologies. In Brazil, this market is still very underdeveloped because of at least two major obstacles. One of them is the investor's joint liability for the new business, which drastically increases the risk of that investment. In most of the world, the investor does not have to assume joint liability for the startup's debt, contrary to the case of Brazil. The Complementary Law nº 155/2016 was an important step in this direction, enabling different exit strategies for leaving the investment and exempting angel investors from being legally answerable for the debt of the startup that received the investment. Another obstacle is the creation of a capital market for this kind of business, which would benefit from a smoother exit process for angel investments.

3.2.4 Allow capital gains tax exemption for venture capital investments in startups, and create mechanisms of public co-investment

The idea is to stimulate private venture capital funds to invest in technology-based enterprises, through tax incentives or government co-investment. Public venture capital funds, such as those managed by FINEP and BNDES, may develop partnerships with private funds to complement the investments of these investors, diluting the investment risk. The United States has several of such incentives and the model adopted there could be a source of inspiration for the changes that Brazil should implement.

3.3 Reducing bureaucracy and improving the business environment

The agenda for improving the business environment is too broad and diversified to be fully addressed within the scope of this work. However, as we have seen, a bureaucratic and rigid environment like the one in Brazil affects investments in innovation even more strongly than it affects conventional investments.

With respect to innovation in particular, improving certain aspects of the business environment is crucial. From this principle comes the following suggestions.

3.3.1 Periodically publish an agenda for improving the business environment

The public sector should consolidate and adhere to an agenda for improving the business environment, identifying precisely which standards, regulations, and legislation could be modified to improve the institutional environment for innovation. This agenda should be published annually so that society could monitor its implementation and demand progress. China, for example, releases these types of documents, which are also used to report to institutions such as the World Bank on the progress made in the country's business environment.

3.3.2 Improve the Innovation Law and the legal framework for S&T

Enforce the Innovation Law (Law nº 10,973/2004, as amended by Law nº 1,3243/2016). This law was created in 2004 and many of its articles have never been observed or have been applied without great effect. Despite the existence of the Innovation Law and other S&T legislation, their practical use is hindered by diverse and sometimes conflicting interpretations. Legal advisors, public prosecutors, federal attorneys, and independent lawyers tend to apply more traditional laws that are often averse to technical change, to the detriment of the possibilities contained in the Innovation Law.

3.3.3 Facilitate the process of starting up and closing down a business

Legislation governing the creation and dissolution of companies should be reviewed in order to facilitate and streamline this process and stimulate entrepreneurship, as well as the required process of creative destruction.

3.3.4 Reduce bureaucracy associated with R&D, especially in the life sciences

Brazilian authorities should reduce bureaucracy associated with R&D, especially in the life sciences. The biodiversity law was a step in this direction, but the issue of bureaucracy should be constantly monitored, evaluated, and updated.

3.3.5 Modernize the National Institute of Industrial Property (Instituto Nacional da Propriedade Industrial – INPI) and speed up the patenting process

This topic has long been on the agenda for improving innovation in Brazil. There should be a more precise diagnosis to determine which factors actually hinder INPI's work, in order to reduce the world's biggest backlog of patent applications.

4 IMPROVING PUBLIC POLICIES

Public policies that shape conditions for innovation, as well as the ways the state invests in the production of science and technology, are crucial to the Brazil's innovative performance. Over the last twenty years, despite the problems, Brazil has been able to expand the range of policies that support innovation, which was absolutely necessary. The results, however, have not been quite as promising as expected.

On one hand, this has been largely due to an economic environment hardly conducive to innovation, as we have seen. On the other hand, public policies should still be constantly improved and reviewed. In the case of Brazil, there remains room for improvement.

4.1 Implement routine mechanisms for evaluating S&T policies

Public policy must be evidence-based: hence the need for indicators and transparency in policy implementation. Unfortunately, Brazilian public policy (not just innovation policies) still lacks transparency, and policymaking is almost never based on sound technical knowledge. These policies can only be improved to the extent that they are constantly evaluated and monitored not only by the government but also, importantly, by society.

4.1.1 Intensify and improve the use of information technologies for collecting and systematizing the information on S&T policies

Transparency and clarity in the provision of information on public policies are fundamental in terms of enabling society and the academic community to monitor implementation. In order to achieve this, it is necessary to incentivize the use of information and communication technologies while collecting, storing, handling, and sharing data on innovation. There is also a need for greater compatibility between public information systems: much of the relevant information on public policies is still stored in spreadsheets by the employees of various agencies in formats incompatible with other public databases. Tools and technologies currently exist to improve access to information of social relevance, such as information on public policies.

4.1.2 Set aside a percentage of the funding for each public policy, to be used for evaluation

Each new public intervention in the area of innovation should include mechanisms for assessing its effectiveness. In addition, each new intervention should be preceded by an assessment of potential impact.

4.2 Applying science and technology to solve Brazil's critical problems

The central point of this recommendation is the need to increase public investment in R&D, especially those aimed at solving the challenges faced by Brazilian society in the fields of energy, health, defense, public safety, and so on.

Much of the world's scientific research is driven by very specific challenges for which national governments provide research funds. One of the major differences between public investments in R&D in countries like the United States and Brazil, as previously discussed, is that in the United States much of public investment in R&D is aimed at solving problems faced in the fields of defense, health, or energy.

4.2.1 Increase R&D investments in the ministries of Health, Energy, Agriculture, Defense, and Public Safety

Ministries with specific missions such as these normally make use of investment in R&D to address concrete problems. These investments would be complementary to those carried out in more horizontal ministries, such as that of Education or of Culture and Technology, whose mission is to foster science and education more comprehensively. Sectoral ministries could foster R&D, for instance, to: i) develop medicines and vaccines for the public health system; ii) develop technologies for increasing energy efficiency or reducing water consumption (in order to mitigate the water crisis); or iii) to create new system technologies for telemedicine that can increase efficiency and reduce the costs of health systems, among others.

4.2.2 Modify the public procurement legislation in order to allow the possibility of R&D contracts

Explicit and clear procedures for contracting R&D for the public sector should be added to Law nº 8,666/1993 (the public procurement law). Article 20 of the Innovation Law already provides for this option, but it needs to be improved and supplemented in order to provide greater legal assurance for the public manager. On the other hand, in order to make technological services more attractive to the private sector, it is crucial that the law permits contracts for the reimbursement of cost in cases of new product development, an option not available under existing law. Brazil should refer to the United States Federal Acquisition Regulation as an example to improve its procurement law.

4.2.3 Strengthen policies concerning technology platforms

This policy, launched in 2014, was aimed at the acquisition of R&D for the development of solutions to problems related to the public interest. The federal government, assisted by a committee of experts and after consultation with the public, would define the problems to be solved, so that public-private consortia of suppliers could develop the solutions. The government would be responsible for defining the problem and not the way in which solutions should be developed or who should develop them. Examples of possible challenges include developing and scaling-up a vaccine against the Zika virus, as well as developing and applying e-government tools.

4.3 Create diverse mechanisms and agencies to support R&D in the country

In addition to public procurement contracts, it is also necessary to create new, agile, and flexible mechanisms through which the public sector may acquire research and development from companies, universities, or research institutions; or, for that matter, jointly develop R&D with these institutions. Interesting examples are the cooperation agreements made by the United States government, or even public-private partnerships that allow for R&D that serves the public interest.

Brazil must create different agency models to support innovation, in addition to FINEP and BNDES (keeping in mind that the latter's focus is not on innovation). The recent creation of Empresa Brasileira de Pesquisa e Inovação Industrial (Embrapii), an agency inspired by Germany's Fraunhofer Society, provides a good example of diversification in the public agencies responsible for innovation. On the other hand, it would be interesting, as part of the attempt to diversify the Brazilian system, to create agencies for developing cutting-edge technology based on the United States model of Defense Advanced Research Projects Agency (DARPA) and Advanced Research Projects Agency-Energy (ARPA-E).

4.4 Improve governance and increase transparency in the selection of projects supported by sectoral funds

We must improve governance as well as the selection process of projects supported by the sectoral funds, ensuring competition and the selection of the best projects, reinforcing the original objectives of the funds. Over the years, much of the funds' budget has been shifted to so-called cross-cutting actions, whose governance and project evaluation criteria are much less transparent.

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