The Impact of United States Competitiveness Policy Reform on Latin America

An Analysis of the CHIPS and Science Act of 2022

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Content

Abstract

This study explores recent endeavors to reshape science and innovation policies within the United States, focusing on reform efforts within the National Science Foundation (NSF), and the potential implications for Latin America. Central to this discussion is the establishment of the new Directorate for Technology, Innovation, and Partnerships (TIP), and the expansion of the NSF budget, alongside the CHIPS and Science Act's provisions. These initiatives are expected to impact global science and innovation policies. While the semiconductor sector in Latin America may see near-term effects, broader changes in research policies are likely to evolve more gradually, akin to past U.S. policy shifts. The reform marks a significant step forward in U.S. science and innovation policy design, albeit falling short of creating an agency dedicated specifically to innovation. The study serves to highlight a broader trend among international science and innovation promotion agencies toward prioritizing innovation and amplifying the impact of research. For Latin American countries, the inquiry revolves around how these reforms will influence national policies, and the strategies of research and innovation support entities. The assimilation of U.S. reforms into Latin American policy frameworks has been a gradual process, with potential to align organizational structures with economic sophistication.

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1. Introduction

This study examines the content of recent initiatives to redesign the U.S. science, technology, and innovation policy, with an emphasis on aspects of the National Science Foundation (NSF) reform and its global implications, in particular for Latin America. Over several decades, U.S. policy reforms have set benchmarks for other countries, leading to the establishment, post-World War II, of pivotal research support agencies in response to crises such as the Sputnik launch, and collaborative frameworks like the Bayh-Dole Act in the 1980s.

Central to this examination is the enactment of the “CHIPS and Science Act of 2022”. The law, passed recently by the U.S. Congress, is an outcome of the drawing together of proposals previously passed by the Senate—the United States Innovation and Competition Act (formerly known as the ‘Endless Frontier Act’)— and the House of Representatives—America COMPETES Act. It reinforces previous initiatives and introduces important elements into U.S. competitiveness policy.

The Act is wide in scope and aims to stimulate far-reaching actions capable of challenging significant commercial and technological rivalry with China. To a certain extent, it repeats the introduction of a federal science and technology system in the immediate aftermath of World War II, when the first U.S. science support agencies were created, as well as the U.S. response to the Soviet Union’s launch of Sputnik I and II at the end of 1957, resulting in the creation of NASA (National Aeronautics and Space Administration) and DARPA (Defense Advanced Research Projects Agency). This marked the beginning of a period of substantial increase in public spending on research and development (R&D)—the so-called golden age of American research. The Act also repeats the U.S. launch of a set of cooperation incentives among academia, national laboratories, and industry in 1980, in response to the challenge posed by Germany, and, to a greater extent, Japan, which—though with a science sector less robust than that of the United States—boasted a more competitive semiconductor industry.

Of particular interest are the provisions within the Act, notably the establishment of the new Directorate for Technology, Innovation, and Partnerships (TIP) within the NSF, and the definition of its budget. These measures extend the NSF’s purview to include initiatives fostering translational research, accelerating technology development, and enhancing workforce skills in strategic domains. The anticipated impact ranges from immediate effects

in sectors like semiconductors, to gradual shifts in broader research policies, reminiscent of U.S. policy transitions, historically.

Review of current reforms is pivotal for Latin American countries, since much of the institutionality of scientific, technological, and innovation policies in those countries was inspired and shaped by U.S. actions and is likely to recur in the coming years. In the post-war period the creation of both NIH (National Institutes of Health) and NSF, encouraged the emergence of many national research support agencies, and led to specific efforts focusing on nuclear energy research. In the following decades, U.S. reforms encouraged a revision of science, technology, and innovation (ST&I) policies, with innovation laws and a strong emphasis on public–private cooperation. The work by Bush (1945), indicating the direction of U.S. science policy in the post-war period, is still one of the most influential studies on these policies.

The ongoing reform will undoubtedly lead to rethinking the world's ST&I policies. But discussion of the breadth of reforms in the United States will also be an opportunity to go further in understanding how such policies can encourage new industrial and competitiveness policy actions in a broad sense, as new legislation proposes to do for the semiconductor sector, complementing U.S. policy initiatives already taken for the telecommunications industry, and 5G technologies.

This study underscores a global trend among science and innovation promotion agencies toward prioritizing innovation and amplifying the impact of research. For Latin American countries, this raises crucial questions about the integration of these reforms into national policies, and the strategic agendas of research and innovation support entities.

In this sense, examining U.S. policy reform yields a comprehensive agenda of key points deserving of attention in Latin American innovation agencies over the coming years. First, the emphasis on critical technologies in the CHIPS & Science Act, underscores the importance of focusing efforts on select pivotal issues, bearing in mind existing scientific capabilities and future challenges. Second, the shift toward mission-driven research aligned with national challenges signifies a significant departure, with the potential to influence global agencies, and prompt Latin American counterparts to align strategies with those of the United States and Europe. Third, balancing curiosity-driven research with use-inspired endeavors becomes imperative for nurturing both scientific exploration and practical application, vital for fostering the next generation of scientists. Moreover, initiatives supporting new innovation hubs and prioritizing diversity and inclusion, are crucial for inclusive growth and tapping into

underrepresented talent pools. Collaborative partnerships between companies, research institutions, innovative organizational structures, and diversified support instruments, further enrich the agenda, demanding adaptive strategies from Latin American agencies so that they cannavigate evolving landscapes in science, technology, and innovation. Given the historical influence of U.S. policies on Latin American frameworks, the assimilation of these reforms is expected to be a gradual, yet transformative process, potentially steering focus toward aligning organizational structures with economic sophistication.

A detailed assessment of this reform and its impact requires review of the way in which U.S. public policy evolved after World War II, as the design of agencies and their missions and priorities have changed over time. These characteristics have gradually adapted to new contexts and responded to external challenges posed to the U.S. economy. A good starting point is the evolution of U.S. ST&I policy and its main agencies.

2. Brief history of U.S. ST&I Policy

Bonvillian (2014) summarizes the key advances in the development of U.S. ST&I policy and the global implications:

> "There have been four major innovation organization policy junctures for the U.S. federal government, driven by the demands of politics and technology since World War II:
>
> - First, the immediate post-war period, when the Cold War helped drive a basic research model for new and expanded science agencies.
> - Second, the Sputnik aftermath with the formation of the Defense Advanced Research Projects Agency and scaled-up funding for science.
> - Third, the competitiveness era “Valley of Death” programs of the 1980s.
> - And finally, a recent energy technology shift, driven by energy and climate demands."

To these four key points in history, a note should be added on the significance of World War II for U.S. science and technology policy since much of what followed is a legacy from this time. In addition, there is the present response to challenges posed by China. The U.S response to challenges to its global leadership at each of those events, if not always swift, was in general comprehensive, with a bold redefinition of policies and redesign of the institutionality and missions of its agencies. Changes in U.S. policy were guided by debates that recur periodically and are still relevant today, with discussions on: the balance between “curiosity driven” and “‘use inspired” initiatives; missions guided by top-down decisions and bottom-up options; and efforts in basic research, applied research, and technological development, examining the role of various agencies set up to account for these policies, and the most recent justifications for altering the NSF design.

The War Effort and Its Legacy to U.S. S&T Policies

It is a well-known truism that warfare results in advances in science and technology that have tremendous consequences (Cohen, 2021). In fact, the U.S. war effort was a breaking point in interactions between science and the federal government.

> " (...) the combination of institutions and Federal support systems, which existed before 1940, was significantly altered during the course of the war. Another impact of the war was to transform the relationships among government, universities, private foundations, and industry. Of these, the most notable change for science was the strengthening of the link between government and universities, but another important outcome was the establishment of the military as a continuing and generous supporter of scientific research and technological development" (House of Representatives, 1986).

Brooks (1986) pointed out this significance in several classic texts, illustrating how World War II was a watershed in the development of U.S. science policy. It was the first time that scientific developments came to fruition and were used in battles during that war:

> "In contrast to World War I, when scientists were brought into the service of the war effort primarily as military officers under the direction of military commanders, the scientific war effort in World War II was organized as an independent civilian enterprise under the Office of Scientific Research and Development (OSRD), directed by Vannevar Bush, and managed by industrial and academic scientists in equal partnership with the military, rather than subordinate to it. Although the work was fully funded by government, it operated outside the Civil Service, with scientists remaining within their familiar institutional settings. Military research and development was conducted under contract to private institutions on an unprecedented scale, with the government bearing all costs, including those of administration and infrastructure ("overhead"), on a reimbursable basis, generally with no profit and no financial gain or loss, to either individuals or institutions. Research contracts with fully reimbursable overheads were a distinctly U.S. invention and proved to be an extraordinarily flexible instrument in the subsequent partnership between government and private

> institutions that evolved in basic research, hardware development, and even policy analysis and system management during the postwar period.[1]

The change was radical and can be gauged by the number of scientists working in the main U.S. industries, totaling some 2,800 in 1921, and close to 27,800 by 1940. At the end of the war, the number had jumped to 45,900. As Stephan (2013) summarized, science emerged triumphant from World War II.

However, one of the most notable features of the war effort, and one that would be the subject of many subsequent discussions on U.S. policy design, was what Bonvillian referred to as a model of connected science:

> "Bush and his colleagues created what we can call a 'connected science' approach, where technology breakthroughs at the scientific level were in close connection with the follow-on applied stages of government-supported development, proto-typing, test beds and production, operating under what can be called a 'technology challenge' model. Not only were the stages of research linked, but the innovation actors were also linked. Government supported all the R&D stages, as well as the implementation stages, encouraging close connections between government, university and industry innovation actors" (Bonvillian, 2014).

1. The Office of Scientific Research and Development was created to replace the National Defense Research Committee (NDRC) to coordinate the scientific research effort for military purposes with almost unlimited funds. The development of the first atomic bomb (the Manhattan Project) was its best-known initiative. Starting modestly in the early 1940s, the project employed more than 130,000 people and cost nearly US$30 billion at today's prices.

The Immediate Post-War Period and the Basic Design of U.S. S&T Institutions

The model of basic research support that influenced the actions of the new U.S. scientific agencies was designed in the immediate post-war period in the context of the Cold War. Bush (1945) inspired much of what later became U.S. science policy.

Stephan (2013) states that no one had understood this context better than Vannevar Bush. It was clear that the timing favored public initiative; Bush was instrumental in suggesting Roosevelt request a report, which was to set the course of federal government action.[2] The work by Bush (1945) would become frequently consulted for subsequent generations, in particular the following recommended actions:

- The government should fund basic research at universities and medical schools because these "institutions provide the environment which is most conducive to the acquisition of new scientific knowledge and are least under pressure for immediate, tangible results".
- The government should provide scholarships and fellowships to promote training. Both research and training initiatives, it argued, were essential for economic growth; both addressed the concern that, due partly to the War, the United States faced a scientific deficit in terms of basic research and the highly trained individuals necessary for conducting the research.
- The government should continue to conduct research of a military nature during peacetime (Stephan, 2013).

Institutions were created in this context that later would become the main research support agencies. For example, in 1946 responsibility for nuclear science fell to the newly organized Atomic Energy Commission, while in 1947 responsibility for basic science shifted from the military to the newly organized DOD. In 1948, the National Institutes of Health, heir to a set of previous initiatives, assumed its current features and the NSF was created in 1950.

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2. The idea that Bush maneuvered for this request is controversial (Bronk,1975; England, 1982; Kevles, 1977), as are the disagreements between Bush and Senator Kilgore (Wang, 1995).

The model put forward by Bush (1945) was a political success, beginning with the premise that U.S. leadership in the Cold War would depend on basic science produced in the country. The NSF, DOE's Office of Science, NIH, and DOD proceeded to fulfil this function; "The network of federal basic research agencies enabled the existence of U.S. federally funded research universities, which have become the world's leading universities. It was a dynamic model which included research grants with a range of missions linked to university researchers competing for basic research grants. But that system was absent from subsequent stages of innovation" (Bonvillian, 2013).

Bush's model was successful both as a guideline accepted by all, and in proposing that government support should focus on basic research, which came to be implemented by virtually all agencies. However, the final design of this postwar reform fell far short of Bush's initial idea of advocating for the creation of a robust research funding agency to coordinate these efforts, using as a model, what had been implemented, during World War II.. What was seen, on the contrary, was a fragmentation, in which the role of NSF became marginal, compared to that of NIH, DOD, and DOE, which all received large budgets.

The reasons for this are well known and originate in the political struggle waged from the early 1940s until the end of the war, between Bush and in particular Senator Harley Kilgore, a dispute which had the effect of postponing the approval of NSF. Kilgore was equally optimistic about support for science and its ability to achieve social and economic goals, but he aimed at a much closer link with political institutions, and less autonomy for the scientific community in drafting the research agenda (Brooks, 1996).[3]

Brooks, with a deep knowledge of this trajectory, goes further in his interpretation of this clash, claiming that the debate also brings up an old question of whether the emphasis should be on disinterested science or science driven by curiosity—or conversely, on science driven by use or applications, a controversy spanning many decades.[4]

Despite Bush's long-standing success, his guiding research priorities began to be contested, particularly in the refined analysis by Stokes (2005), where, in a seminal critique of Bush's vision, he states in no uncertain terms that the institutional design proposed in The Endless Frontier was a failure, but its ideological vision prevailed.

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3. For details of this clash and congressional proceedings, see: https://en.wikipedia.org/wiki/Harley_M._Kilgore.

4. See Brooks (1996) mention of the debate in the 1930s between Polanyi and Bernal. It should be noted that Kilgore not only had advisors from industry but received strong support from academia.

As Bonvillian (2013) asserts, although the initial proposal was to structure the research agenda under the coordination of a single organization, the creation of NSF was delayed and in the interim, other agencies were formed. Although Bush's concept of federal funding focusing on basic science prevailed, his more centralized model of support for science did not. The result was a new generation of highly decentralized scientific agencies, each adopting its own pipeline model for the federal role of science: on one hand a fragmented system and, on the other, one that was disconnected.

Stokes (2005) summed this up with the idea that Bush proposed two aphorisms: The first, that basic science is conducted with no concern for practical purposes; the second, that advances in basic science will be converted into technology through technology transfer processes, shifting from basic research to applied research, development, production, or operations. Stokes called this a linear model, as though there were an inexorable path from basic, to applied research, and says this leads to the conclusion that any nation will recover the technological benefit of its investment in basic science.

Pasteur's quadrant is an expression of the following: There may be as much basic science here as in other curiosity-driven research. What distinguishes the quadrant is not whether it contemplates basic science or not, but rather whether its motivation is inspired by use.

Drawing on the observations of Brooks, Branscomb (1999) shows research motivations as falling into two categories: opportunity-driven research, which pursues the visions of scientists, and needs-driven research, which responds to the needs of society. The priority assessment for needs-driven research can be quite different from that of opportunity-driven science, even where researchers' motivations are the same. While opportunity-driven research is proposed and assessed in a competitive horizontal environment (peer review is the prevailing mechanism), needs-driven research derives its priority from vertical relationships. Needs are typically expressed in terms of some capability to be realized through technology, which in turn can derive its conceptual framework and future evolution from a new science (Branscomb, 1999).

The Sputnik Effect

The post-war scenario changed radically with the Soviet Union's launch of Sputnik 1 in October 1957. Launius (undated) testifies that this had a "Pearl Harbor" effect on U.S. public opinion:

> "Not only had the Soviets been first in orbit, but Sputnik 1 weighed nearly 200 pounds, compared to the intended 3.5 pounds for the first satellite to be launched in Project Vanguard (...) Even before the effects of Sputnik 1 had worn off, the Soviet Union struck again. Less than a month later on 3 November 1957, it launched Sputnik 2 carrying a dog, Laika. While the first satellite had weighed less than 200 pounds, this spacecraft weighed 1,120 pounds and stayed in orbit for almost 200 days."

Although slow, the U.S response—a consensus between the White House and Congress—was decisive, as evidenced by the creation in 1958 of both the Advanced Research Projects Agency (ARPA) (later the Defense Advanced Research Projects Agency (DARPA), and the National Aeronautics and Space Administration (NASA), as well as by the significant increase in the budgets of all U.S. research support agencies.

As Smith (1990) points out, this led to an increased technical capacity of the Office of the Secretary of Defense, with ARPA dedicated both to the technological development in sectors of the armed forces, and to support of the advancement of scientific knowledge relevant to long-term military goals.[5]

Reflecting on the legacy of Bush, Stokes (1995–6) underscored this very point in the U.S. response to Sputnik:

> "What is significant about the country's response is that we regarded it not just as a challenge to a piece of our technology, but as a general scientific challenge. The years after Sputnik were years of soaring budgets for almost all branches of science, so that the technology coming out of the other end of the pipeline, according to the linear model, would be our technological surprises, and not theirs."

As these authors illustrate, the Sputnik crisis had a direct effect on the structure and operation of the U.S. R&D system. The creation of NASA added another element of diversity to

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5. See also Bonvillian, Van Atta, and Windham (2019).

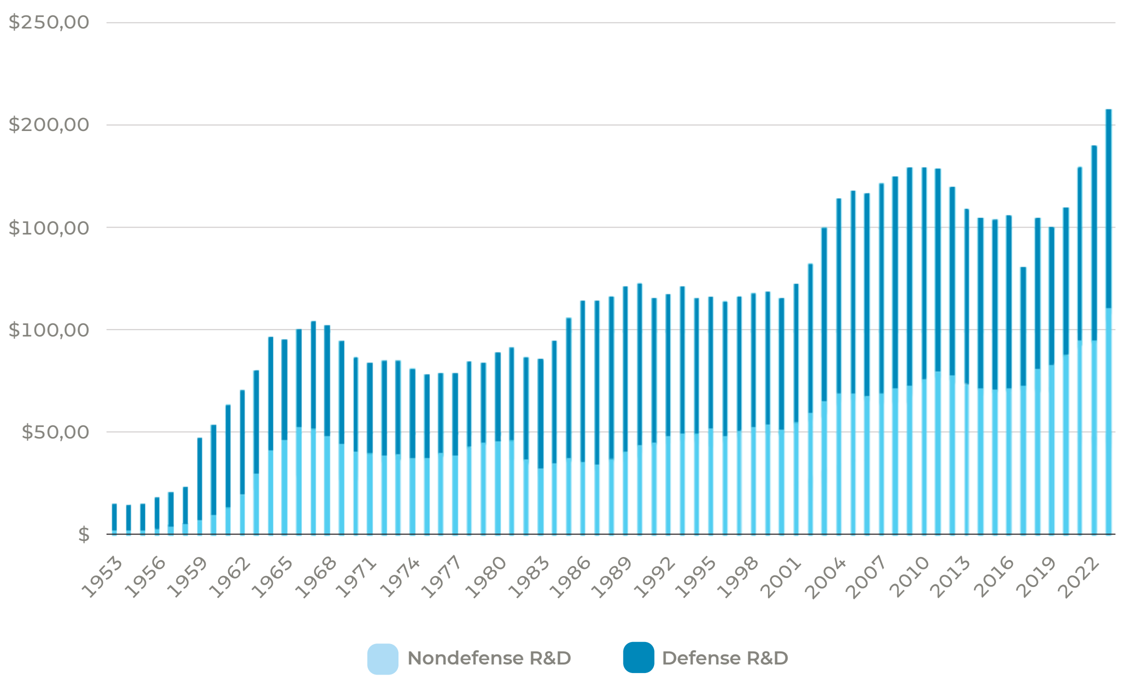
the government's already pluralistic research complex. Fears of impending technological inferiority also helped build political support for further government spending on education and more basic, as well as applied, education. The post-Sputnik era ushered in what has become known as the golden age of U.S. research, with a significant increase in federal R&D budgets.

Annual spending on non-defense R&D jumped from an average of US$3.6 billion between 1953 and 1958, in constant 2022 dollars, to US$12.8 billion between 1959 and 1962, reaching US$30 billion in 1963, US$41.8 billion in 1964, and US$53.1 billion in 1966 (Figure 1). This growth did not affect defense spending; on the contrary, spending in the defense sector also spiked, growing from an average of US$15 billion between 1953 and 1958, to US$40.1 billion in 1959, and to over US$50 billion between 1961 and 1965, finally reaching US$55.5 billion in 1966. Total U.S. federal R&D spending increased by over 3-fold between 1953 and 1959, and then doubled in 1966 in constant dollars.

By the end of the 1950s, 80 percent of U.S. spending on R&D went to the defense area. This percentage would fall in the following decade to about 50 percent, due, not to cuts in defense spending, but rather to the enormous growth of nondefense spending. Regardless, as Mowery (2009) declares,

> "U.S. science and technology policy was the product of loosely coordinated decisions made in various policy areas (including procurement policy), designed to advance the missions of individual federal agencies. By far the most important of these missions throughout the postwar period in terms of political consensus or budget, was national security."

Figure 1. Federal R&D, Defense and Nondefense (in constant US$ billions 2022)



Source: AAAS (undated): Annual AAAS R&D budget reports. Data for 2023 is from the requested budget.

The Competition with Japan and the "Valley of Death"

The success of the Apollo Program and mission to the Moon confirmed the supremacy of the United States in the space race. Today, this would inspire a whole series of ST&I policies called mission-oriented or—in memory of this race—simply moonshots.

But following the Sputnik scare, the United States was again shaken, this time in the face of industrial competition with Germany and especially Japan. In addition to implementing a highly innovative manufacturing model focused on quality and incremental technological advancements, Japan also gained expertise in the licensing of intellectual property, which had originated in the United States. Bonvillian (2014) called this moment the "Valley of Death" since the biggest challenge for the United States lay in the gap between research and development in the more mature stages of technology.

Japan's biggest challenge came from the new semiconductor industry. Its research institutions and companies had limited scientific and technological knowledge in this area and were beginning the process of imitating what was being developed in the United States.

Dosi (2006) analyzed this process in detail and showed how Japan made an institutionally well-coordinated and targeted effort to set technological targets and build technical capacity by combining restrictions on foreign investment and imports under a policy to publicly monitor the terms of technology licensing agreements. Goals based on a broad "corporate" consensus—agreed on by companies, the central government, and unions—generated a remarkably effective relationship between institutional structures, as well as an extremely competitive internal market environment among the main Japanese groups.

According to Nagaoka and Flamm (2009), the United States first became aware of Japan's technological capabilities in the late 1950s, when Japan succeeded in mastering the production of transistors for cheap consumer electronics. In the decades that followed, Japanese companies copied, adapted, and perfected a host of high-tech products still focused on consumer goods, such as television sets, calculators, and digital watches. The cycle between an early American innovation and a successful Japanese improvement and, ultimately, market dominance, became shorter and shorter. The same was true in the automotive industry. In both cases, Japanese advancements concentrated on continuously improving manufacturing processes, increasing product quality, and on reducing production costs. The success of this trajectory became clear when Japanese companies came to dominate Dynamic Random Access Memory (DRAM) technologies.

Because of its fragile local scientific base and reduced capacity to produce basic research, Japan was a conundrum to the Americans. The reaction in the U.S was a heated debate on industrial and technological policy. It was apparent that the country needed to look also at the market, and at more efficient technology transfer and cooperation mechanisms used by actors in the innovation system.

The reaction and change in U.S. innovation policy are noteworthy for the size and quantity of legislative amendments passed since the early 1980s. The following are worth mentioning:[6]

6. For a more detailed list of these initiatives see Shapira and Youtie (2010). Among the initiatives of this period that did not thrive was the creation of a national technology foundation to complement an NSF. See Bill H.R.6910 of 1980, as well as the Branscomb (1980) testimony to the House of Representatives Subcommittee on Research and Technology and *Science* (1990).

1. The Stevenson-Wydler Technology Innovation Act (1980): The Cooperative Research and Development Agreement (CRADA); a legal instrument authorizing national laboratories to undertake joint projects with industry.
2. The Bayh-Dole University and Small Business Patent Act (1980) granted patent rights over government-funded research to universities and encouraged them to actively transfer technology to private industry.
3. The Small Business Innovation Research (SBIR) program (1982) provided competitive R&D grants to small and new businesses managed by the Small Business Administration (SBA), which also oversaw a related initiative, the Small Business Technology Transfer (STTR) program.
4. The creation of a Court of Appeals of the Federal Circuit ((1982) aimed at strengthening the U.S. patent regime in defense of the rights of patent holders (software patentability – 1990).
5. The National Cooperative Research Act (NCRA) (1984) allowing industry R&D consortia a certain immunity from U.S. antitrust laws. In 1993, this immunity was extended to production joint ventures.
6. Engineering Research Centers – National Science Foundation (1984): NSF began allocating funds to Engineering Research Centers designed to promote collaboration between universities and businesses.
7. The Federal Technology Transfer Act: CRADAs (1986) authorizing national laboratories to enter into cooperative R&D agreements (CRADAs) and negotiate licensing agreements.
8. The Omnibus Trade and Competitiveness Act (1988) changed the name of the National Bureau of Standards to National Institute of Standards and Technology and expanded its mission; it also established manufacturing technology transfer centers.
9. The National Competitiveness Technology Transfer Act (1989) extended the CRADA model to all federal laboratories, including defense industry laboratories.

The Bayh-Dole Act is perhaps the best-known initiative in this generation of legislation enacted in order to support competitiveness. Prior to the Act, the government owned the results of publicly funded research. The Act transferred ownership of the results of federally funded research to universities, giving them a stake in the commercialization of such results. Although the effects of the Law are controversial, many authors interpret it as a success, since it enhances the role of universities in the so-called "connected" science (Mowery, et

al., 2004).[7] Gradually, universities set up technology transfer offices and began to build innovation support systems to assist their researchers and connect with companies. Many other countries were inspired by this Law and established similar systems, as pointed out in OECD studies. One such country was Brazil, with its Innovation Law incentivizing the creation of NITs in universities (Mowery and Sampat, 2005; Mowery et al., 2004). Although fostering a closer relationship between universities and companies requires much more than legislation inspired by the Bayh-Dole Act, these emerge precisely when studies on scientific and technological development are once again highlighting the complex nature of national innovation systems and the synergistic relationship between their various actors.

ARPA-E and the Challenge of Reforming the U.S. Energy Sector

At the frequency suggested by Bonvillian (2014) for the major reforms of U.S. ST&I policies, a fourth relevant moment summarizes the set of initiatives driven in recent decades by the challenges of climate change and the search for energy sources as alternatives to fossil fuels. Its critical point is the creation of the Advanced Research Projects Agency – Energy (ARPA-E), undoubtedly inspired (as its name suggests) by the DARPA model, but which also introduces some new aspects. The ARPA model, as well as the novelties introduced, stems from what it correctly indicates to be the biggest challenge of the energy sector: producing competitive solutions from the outset, with technologies already on the market.

The creation of ARPA-E was recommended by The National Academies (2007) and strongly supported by the U.S. Congress. ARPA-E incorporated several approaches inherited from DARPA, such as a non-hierarchical structure; appointing program directors; fostering streamlined and solution-oriented decision-making processes; and conducting research into significant technological challenges to seek out disruptive advancements. However, over and above these approaches are new elements in the ARPA model, supporting the implementation, commercialization, and deployment of innovative technologies, in an effort to gain over traditional R&D agencies, in development of the pipeline. As with previous reforms, the creation of ARPA-E coincides with a significant increase in U.S. spending on research, a fact that also characterizes reforms currently underway (Figure 1).

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7. A skeptical view of the Act is expressed by Mowery et al. (2004): "The effects of the Bayh-Dole Act (...) were more modest than many assessments suggest, however, the Bayh-Dole Act facilitated the entry into patenting of a number of institutions with little experience in managing patenting and licensing activities. These novice patenters did indeed receive less heavily cited patents initially, but by the end of the 1980s their patents were cited no less intensively than those assigned to 'experienced' academic patenters and (like the patents assigned to 'experienced' universities) were more heavily cited than non-academic patents in the same classes."

3. The CHIPS and Science Act: Recent Reforms

Despite the U.S. scientific community's criticisms of the Trump administration, there have been few negative practical consequences in the field of science and technology, owing to the U.S. Congress' active role in preserving the budgets of the main research support agencies (Mervis, 2020) . The Biden Administration embarked in a very different direction from that of the previous administration, for example, by beginning with raising the status of the Office of Science and Technology Policy (OSTP) to Cabinet level.

To understand the initiatives of the new administration, it is important to note that many of the announced novelties were already under discussion in U.S. Congress before the new president took office. Most of the proposals under discussion since 2020 stem from a clear and growing nationalist and anti-China approach taken by Congress, such as bills to protect Taiwan, or sanctions against Chinese high-tech companies.

The reforms currently under discussion are a clear repeat of the key moments summarized in the opening of this article, and are U.S. responses to challenges posed by other countries to U.S. leadership in the field of science and technology. The recent reform of the U.S. ST&I system is a direct response to the competitive challenge now posed by China. As Bonvillian (2021) stated in his testimony to the U.S. Senate during consultations on The Endless Frontier Act: "Strong competitors are making economic and technological advances which threaten to displace U.S. leadership. Our current systems are simply not competing well. This requires us to adopt a new advanced technology strategy. Without it the United States will in all likelihood continue to lose market share in a host of advanced industries, including aerospace, life sciences, semiconductors, advanced communications and protocols, and Internet applications, with negative implications for innovation, national security, and, importantly, living standards (...) (U.S. citizens)."

The CHIPS and Science Act of 2022 is, for example, the result of the reconciliation of different legislative initiatives passed by the U.S. Senate and House in 2020 and 2021. This topic

was first introduced in the U.S Senate in May 2020 in the form of "The Endless Frontier Act" (Senate, 2020), which aimed to solidify U.S. leadership in scientific and technological innovation through increased investments in the discovery, creation, and commercialization of technological fields of the future, in the face of advanced technology competition from China (Bonvillian, 2022). This proposal eventually evolved into a new legal provision, the Innovation and Competition Act (Senate, 2021) passed in 2021, which now includes, among other things, measures to support the semiconductor industry, as well as new programs for the NSF and Department of Commerce.

In the House of Representatives (2021), in the context of laws re-authorizing NSF and NASA programs, the Committee on Science, Space, and Technology passed legislation with similar objectives—though with a greater emphasis on social objectives—also authorizing new NSF programs. A brief comparison of these instruments explains the initially diverging perspectives of the two houses (Akin Gump Strauss Hauer & Feld, 2022; CPC Center, 2022) (Table 1).

Table 1. Comparison of Instruments in the U.S. Senate and House of Representatives

SENATE	HOUSE
• Created the Technology and Innovation Directorate at NSF with the purposes of: (i) strengthening leadership in critical technologies; (ii) addressing challenges to the U.S. strategic position; (iii) increasing competitiveness by improving education in key technologies; (iv) accelerating the translation of scientific advances in key areas; (v) avoiding undue geographical R&D concentration; and (vi) contemplating a perspective of the workforce of labor organizations. • Focused on selected technologies: (i) artificial intelligence (AI), machine learning; (ii) high-performance computing; (iii) quantum science; (iv) robotics, automation, and advanced manufacturing; (v) prevention of natural and man-made disasters; (vi) advanced communications technology; (vii) biotechnology, medical and genomic technology, and synthetic biology; (viii) data storage and management and cybersecurity; (ix) energy efficiency and batteries; and (x) advanced materials science. • A new program of University Centers for basic and applied research, development, and commercialization of innovations in key technologies. • A new program in Innovation Institutes of partnerships between universities, institutes, and companies, for the development and commercialization of innovation in the primary areas of technology focus. • Authorized a significant increase in NSF funding overall, with an increasing share for the new Directorate (US$81 billion for NSF and US$29 billion for the new Directorate in the period 2022 to 2026).	• Authorized NSF to invest in critical research infrastructure with the goal of pursuing broader impacts, such as increasing competitiveness, supporting U.S. national defense, and enhancing partnerships between academia and industry. • Set up an office to coordinate all research security issues; established a program to curb misconduct and violations of research integrity; and prohibited the participation of NSF researchers in talent recruitment programs sponsored by foreign countries of interest. • Research reproducibility and replicability: required easy public access to research products, including data, software, and code. • Support for research on climate change: human behaviors; earth system; risk, vulnerability; resilience and adaptation and mitigation capacity; design; development and evaluation of decision support information; modeling; projections; climate analysis and assessment; atmospheric processes linked to solar radiation; strategies to train climate change researchers and mitigation professionals; strategies for public engagement in all stages of R&D. • Measurement of federally funded R&D impacts: indicators and associated analytical tools to enable a better understanding of impacts on society, the economy, and the workforce. • Support for the following lines of research: violence; behavioral sciences; food-energy-water system; biological field stations and marine laboratories; sustainable chemistry; risk assessments and predictability, including data analysis and the use of AI; unmanned aerial vehicles; water resources; advanced manufacturing; critical minerals; artificial intelligence, Internet in agriculture.

The proposal submitted to and passed by the Senate focused heavily on issues of competitiveness, such as critical technologies, while the House's proposal placed greater emphasis on the dimensions of social impacts, through scientific research topics. A reflection of these differences is also the prominent role taken by the Senate in this version of the Law, toward the new NSF Directorate, which, at the end of the period and considering the planned authorizations, would be responsible for no less than 43 percent of NSF's overall budget. Also noteworthy is an aspect that the final draft of the Law failed to consider: The Senate included, in its previous draft, the list of key technologies to be prioritized, and which in the final draft, would be the duty of NSF. The Foundation was to submit its list of priorities on a regular basis to Congress, for a maximum of 10 technologies.

The final draft of the Law was negotiated in a multi-month conference between the committees of both legislative houses, and represented a compromise that merged the two initial approaches. The final draft was passed in August 2022 and included funding from both the CHIPS Act, and pre-appropriations for more general NSF actions. But while the first were final approvals, the latter were only provisions rather than real appropriations of funds, and these required final approval by Congress. Although bipartisan support could signal greater ease in approving these appropriations, it was a complex process that would still need final confirmation, given the context of fiscal constraints that will be discussed below (Bonvillian, 2022).

Bonvillian (2022) pinpoints the main characteristics of the legislation on final approval: the creation of the new NSF Directorate for Technology, Innovation and Partnerships (TIP) with a five-year budget of US$20 billion, the main reform of NSF in the past thirty years; the requirement that TIP should support no more than ten critical technologies; TIP's emphasis on the transfer of critical technologies between universities and industries; the authorization for NSF to fund the development, demonstration, and deployment of new technologies, in addition to research, which was its focus in the past; the effort to stimulate new local innovation arrangements in less developed areas; and the obligation of the Office of Science and Technology Policy (OSTP) to submit a National Science and Technology Strategy to Congress.

In addition to these provisions, the Act incorporates numerous other initiatives, such as science, technology, engineering, and mathematics (STEM) training programs; support for less-established research universities; new responsibilities for the National Institute of Standards and Technology (NIST) and the Department of Commerce; support for regional technology hubs; support for the Manufacturing Extension Partnership (MEP) Program

and Manufacturing USA Institutes Program; as well as an increase in the Department of Energy's R&D budget, and NSF's overall basic science support budget.

As Bonvillian (2022) summarized, the law seeks to position the United States to compete with China's major programs, and while its emphasis on innovation was toned down in the draft agreed on by the House of Representatives, it represents a clear shift from the former focus on basic research advocated by Vannevar Bush, and implemented by U.S. policies for decades. This new law explicitly emphasizes stages such as development, prototyping, demonstration, scaling, pilot plants, initial batches, and production. These translate into numerous programs created and strengthened in order to support the development and transfer of critical technologies, including the creation of the new NSF Directorate for Technology, Innovation and Partnerships, since NSF is the largest R&D agency not bound to a mission.[8]

Notwithstanding the strong emphasis on new actions to support innovation, implementing these new policies in the context of an old and well-established institutional framework—in which agencies have deeply rooted institutional cultures—will be a major challenge (Bonvillian, 2022). Adding to this challenging scenario, the CHIPS and Science Act brings with it many promises and a wide range of initiatives, but most of them are devoid of any detail on how they will be implemented.

In addition to these concerns, some have argued that the new design will create a cultural shock within NSF, given its historical focus on basic research. It is also argued that the emphasis on applied research could erode support for basic science, affecting the development of technology itself in the long run. The long history of the United States in applied research may help to facilitate the success of CHIPS and Science, and that agency cultures can be complementary, with ARPAs operating in tandem with NSF; however, the answer to the question of how to combine these diverse roles is far from simple.

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8. Bonvillian (2022) notes that it is ironic that the original initiative was called "The Endless Frontier Act," as it was far from the emphasis on basic research proposed by Bush (1945).

The Primary Purposes of the New Directorate for Technology, Innovation and Partnerships

The CHIPS and Science Act extends beyond the traditional function of the NSF and establishes the purposes of the new directorate as follows:

1. Supporting use-inspired and translational research and accelerating the development and use of government-funded research.
2. Strengthening the competitiveness of the United States by accelerating the development of key technologies.
3. Strengthening the upgrading of the domestic workforce in key technology areas and expanding the participation of U.S. students and researchers in areas of social, national, and geostrategic importance, at all education levels.

It is also important to highlight the intention of U.S. Congress to focus on and prioritize certain topics through action to:

- Support transformational advances in use-inspired and translational technology research and development.
- Encourage the translation of research into innovations, processes, and products.
- Develop R&D partnerships and collaborations among institutes of higher education, with a focus on minorities.
- Strengthen partnerships with other foundation directorates and offices for specific projects or research areas.
- Build capacity and infrastructure for use-inspired, translational research in institutes of higher education.
- Support the education, mentoring, and training of undergraduate and graduate students and postdoctoral researchers.
- Identify social, behavioral, and economic mechanisms that drive advances in key technology focus areas.

The negotiation between the Senate and the Brazilian Chamber of Deputies eventually took the form of a list of key technologies and priority social challenges. The original bill passed by the Senate referred only to key technologies and established a maximum of 10

technologies subject to review, but it already indicated an initial selection that was validated in the final draft of the Act (Section 2005 of the Endless Frontier Act) (Senate, 2021).[9]

Along with the emphasis on mission-oriented research—though this term is not mentioned in any of the legal instruments discussed in Congress—the negotiation in the final draft of the Law also included five areas of focus in order to address major national and social challenges. These areas are in accordance with what had been approved in the Chamber of Deputies, which emphasized many more aspects related to these challenges beyond the key technologies [10] (Senate, 2021; House of Representatives, 2022).

Challenges of Moving ST&I Policy Toward Innovation

Past success of policy changes in science, technology, and innovation for maintaining overall U.S technological leadership is, in the current economic climate, harder to achieve. This, in part, due to global interdependence of advanced technology chains, and hindrances to nearshoring, or similar actions, rather than to globalization. Limitations stem from, for example, the difficulty of effectively separating the U.S. and Chinese economies, whose trade flow today is several hundred times greater than that of the United States or than that of the Soviet Union in the past. Other limitations—particularly regarding semiconductors, or

9. Artificial intelligence, machine learning, autonomy, and related advances; high performance computing, semiconductors, and advanced computer hardware and software; quantum information science and technology; robotics, automation, and advanced manufacturing; natural and anthropogenic disaster prevention or mitigation; advanced communications technology and immersive technology; biotechnology, medical technology, genomics, and synthetic biology; data storage, data management, distributed ledger technologies, and cybersecurity, including biometrics; advanced energy and industrial efficiency technologies, such as batteries and advanced nuclear technologies, including, but not limited to, for the purposes of electric generation; advanced materials science, including composites 2D materials, other next-generation materials, and related manufacturing technologies. Senate (2021), S1260. United States Innovation and Competition Act.

10. The Competition Act passed by the House contained the following list: climate change and environmental sustainability; global competitiveness and domestic job creation in critical technologies; cybersecurity; national security; STEM education and workforce; social and economic inequality. The final draft modified this list slightly: national security; manufacturing and industrial productivity; workforce development and skills gaps; climate change and environmental sustainability; inequitable access to education, opportunity, or other services. Senate (2021), op. cit. and House of Representatives (2022), op. cit.

other technology-intensive value chains—stem from the fact that many critical stages are now worldwide, rather than concentrated, as they once were, in the United States.[11]

In this regard, subsidies received by the semiconductor industry as a result of the CHIPS & Science Act, though likely to stimulate U.S. chip production and related R&D activities, cannot reverse China's position as the leading producer of basic CHIPS, nor will they alleviate the acute chip shortage faced by the global industry in recent years (Hufbauer and Hogan, 2022).[12] [13]

These difficulties are significant in terms of the specific dimensions of the interface between science policy and innovation policy, speaking of the so-called "scientific" part of the CHIPS and Science Act. This calls for discussion of, for example, how the proposals will be adapted to the various existing institutional cultures; difficulties in coordinating the actions proposed; the lack of an agency with an effective mandate to boost innovation in the United States; or perhaps the most critical aspect, the budget authorizations may be extremely difficult to secure, at least as they were initially envisaged, in the face of the current U.S. fiscal climate.[14]

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11. In the case of semiconductors, as shown by Nikkey newspaper surveys, some productive activities and technical skills are very difficult to reproduce in countries such as Japan, South Korea, Taiwan, Belgium, Germany, the Netherlands, and Switzerland, and therefore outside the United States. See Ting-Fang and Li (2022); Mondschein, Welburn, and Gonzales (2022); and Khan, Mann, and Peterson (2021). On the difficulty of qualified human resources, see Shivakumar, Wessner, and Howell (2022).

12. The authors also show that these subsidies are relatively small compared to the capital and R&D expenditures estimated for U.S. industry in the coming years. Abbot (2022) also points out that subsidies should imply increasing domestic semiconductor production, but that there are many challenges that can mitigate the positive impacts of the Act, such as economic factors, logistical bottlenecks, trade wars, geopolitical changes, and technical barriers.

13. For an assessment of the positioning of major countries in light of the CHIPS & Science Act, see Sutter, Sargent, and Singh (2023).

14. Authorization bills—like much of the CHIPS and Science Act—may recommend allocating funds to the agencies and programs to which they refer, but their recommendations are not final. The laws that define what the agencies' budgets are going to be are called appropriation bills, which in the case of the CHIPS and Science Act applies only to its initial part on semiconductor policy.

Budgets of the Directorate for Technology, Innovation, and Partnerships

The CHIPS and Science Act proposed to increase the budgets of the main U.S. research support agencies generously. In the case of NSF, the authorized budget (authorizations) for the period 2023 to 2027 totaled US$81 billion, an increase of US$36 billion compared to the previous estimate (Table 2). The new Directorate for Technology, Innovation and Partnerships (TIP) would receive US$16.3 billion for the same five-year period, and by 2027 it would account for 22 percent of NSF's overall budget, the most ambitious goal in terms of budget increase of the entire new Act.

Table 2. CHIPS and Science Act: NSF Authorized Budget, 2023–27

AUTHORIZATION	2023	2024	2025	2026	2027	2023-2027
National Science Foundation	11.9	15.6	16.7	17.8	18.9	81.0
TIP	1.5	3.4	3.6	3.8	4.1	16.3

Source: House of Representatives HR 4346, The CHIPS and Science Act of 2022.

However, proposals submitted by the Executive to Congress and the approved budgets (appropriations) show that these new allocations are still a long way from materializing. As Hourihan, Muro, and Roberts Chapman (2023) point out:

> "In spite of ongoing support (...) from many political leaders, neither the FY 2023 Consolidated Appropriations Act, nor the Biden Administration's FY 2024 budget request, have delivered on the intended funding targets. This year's omnibus funding remained nearly US$3 billion short of the authorized levels for research agencies, while the 2024 budget request undershoots agency targets by over US$5 billion. And with the debt ceiling crisis (...) it's even harder to be optimistic about the odds of fulfilling the CHIPS and Science Act's vision of resurgent investment in American competitiveness."

Table 3. Authorized and Appropriated Budgets, NSF, DOE and NIST, 2023 and 2024

AGENCY	CHIPS FY23	FY23 OMNIBUS	CHIPS FY24	FY24 OMNIBUS
	Authorization	Appropriation	Authorization	Appropriation
National Science Foundation	11.9	9.9	15.6	11.3
TIP	1.5	0.9	3.4	1.2
DOE Office of Science	8.9	8.1	9.5	8.8
National Institute & of Standards Technology	1.6	1.7	1.7	1.6
Total	22.4	19.6	26.8	21.7

Sources: Federation of American Scientists (2023); Hourihan, Muro, and Roberts Chapman (2023).

For NSF and the new TIP directorate, total funds authorized and appropriated left much to be desired. For the years 2023 and 2024, the amount forecast for TIP totaled US$4.9 billion. However, the funds appropriated for the directorate did not exceed US$2.1 billion. This contrasts sharply with the budgets of the Department of Energy's Office of Science and for NIST, where the amounts authorized are extremely close to what was provided for in the CHIPS and Science Act (Table 3).

A New U.S. Agency Focused on Innovation

Despite the advances proposed in the CHIPS and Science Act for promoting innovation and recommending a special attention to a set of critical technologies, over and above strengthening the role of innovation hubs and emphasizing the training of human resources in STEM, there was some criticism of the wording agreed on by the Senate and the House. Analysts who are more familiar with industrial policy point out that the United States lacks a technology agency dedicated specifically to this agenda. Atkinson (2021) has advocated for a more active stance on the part of the U.S. government regarding innovation, although he recognizes that, due to congressional resistance to play more active roles in the federal executive branch, the initiative is challenging:

> "What the United States lacks and desperately needs is a free-standing federal entity whose sole mission is to support advanced technology industry development, in order to help America compete."

He adds, with some vehemence, that NSF and academic science play key roles in the advancement of basic science, which are different than supporting technological innovation and value capture in the United States is critical, in order to make these advances. [15]

In a sense, this reiterates the previously mentioned fact that Congress has sometimes discussed, but not advanced, a proposal for the creation of a National Technology Foundation, as suggested by Representative George Brown Jr. (D-CA), chairman of the House Committee on Science and Space Technology between 1991 and 1995.[16]

What lies behind this is the idea that, more than generic competitiveness policies, what the United States needs is a strategic industrial policy, focused on key technologies and industries. This would entail using the skills to design policies with a focus on these strategic technologies and industries, possibly through an Advanced Technologies agency linked to either the Department of Commerce or the National Security Council to ensure, at a minimum, that strategic industry concerns would receive greater attention in other agencies and in the interagency process (Atkinson, 2022) .[17]

Recent economic challenges have fueled a debate about the best innovation strategy for the United States. Gerstel and Goodman (2020) suggest certain principles based on observations and lessons from previous American, European, and Japanese experiences, making it clear that despite the consensus on the need for new policies, there is significant disagreement over how to develop them.[18]

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15. "The scientific community resisted the idea that government would be asking them to do work related to a critical national mission, and to hold them accountable for ensuring that their work helped accomplish that mission. They wanted more money, to be sure; but what they wanted even more was freedom." Or: "The university science community uses the "Bush Bible" to resist any and all intrusions from the state to direct their work" (Atkinson, 2021).

16. See, for example, the National Technology Foundation Act of 1980 (H.R. 6910) or the National Technology Foundation Act of 1985 (H.R. 745). See: https://www.congress.gov/bill/99th-congress/house-bill/745

17. As the author points out: "Overall economic growth—and even generic competitiveness policy—is not enough. With the rise of China (...) the United States needs a strategy, policies, and institutional capabilities to ensure it has adequate production and innovation capacity in key industries, especially technologically sophisticated ones."

18. The authors suggested priorities include improving STEM education, increasing funding for programs that transition R&D to the market, attracting foreign talent, leveraging government purchasing power to create market for early-stage technologies, and enhancing policymakers' technical knowledge.

Possible NSF Challenges to Fulfilling the Innovation Promotion Mandate

Another criticism similar to the lack of an innovation-focused agency is that the culture forged over decades of NSF success conspires against the task suggested by the CHIPS and Science Act. In this regard, Atkinson (2022) expresses:

> "Indeed, since NSF's founding, policymakers have occasionally tried to get NSF to focus on broader missions, such as spurring industrial innovation (the Engineering Research Centers program), or technical training (the Advanced Technological Education program). But NSF's leadership and culture have largely rejected these initiatives as foreign bodies, confining them to a lesser status within the agency, where they can do no harm to its core mission of funding basic science."

Still other critics point out that the legislation should have gone far beyond associating innovation with the research agenda. Atkinson cites Windham, Hill, and Cheney (2020), who argued:

> "The idea that university research can and should be the key driver of U.S. technology development and commercialization is a limited and outdated model."

On the scientific community's side, as evinced in the hearings held by the Senate and the House during the discussion of the bills, concerns emerged that the insertion of a new technological mission could divert NSF's core mission of supporting basic science.

Droegemeier (2021) expressed this clearly by underscoring the potential risk that the new directorate could displace and replace fundamental research:

> "The very size and reach of our technology enterprise suggests care needs to be taken in creating a technology directorate at NSF, lest technology become the focal point for new resources, and ironically end up harming the very thing upon which it depends for continued success—fundamental research."

Droegemeier (2021) further suggests that if the Act sought to bring more of a DARPA-like culture to NSF, it should not confine those attributes to the new directorate, but rather

use that directorate to help infuse positive change throughout the Foundation. By doing so, NSF program officers would become more empowered in going against the flow and placing big bets on ambitious ideas, with some failure not only as an expectation, but rather a desired outcome, as the absence of failure indicates an absence of boldness. That is, not only may NSF not be sufficiently equipped or culturally prepared for the new functions, but greater damage may be caused to the agency's current responsibilities. This is reflected by Windham, Hill, and Cheney (2020):

> "This new mission would not fit well with NSF's existing basic research culture, and it would be a shame to damage the existing agency and its programs in an effort to turn NSF into something that it's never been."

The NSF Innovation Engines Communities

The demand from the broad congressional coalition that supported the CHIPS and Science Act, also led to the expansion of NSF's mandate, with the creation of the Regional Innovation Engines program (Section 10388), to support the strengthening of new regional innovation ecosystems.[19] The aim was to increase investment in R&D activities in regions that had not previously benefitted from investments in technology-intensive activities, and thereby expand the innovation capacity through transdisciplinary, collaborative research, inspired by use, translation, and technological development in key areas of technological focus.

The U.S. Congress aims to support the development of less consolidated ecosystems, and in geographically and socially/economically diverse groups, through the establishment of partnerships between industry, academia, government, non-profit organizations, civil society, and communities of practice. The focus is on the search for diversity and greater attention to minorities through the dissemination of a culture of innovation and the improvement of workforce education and training in these regions, with economic and social impacts aligned with local needs.

19. The CHIPS and Science Act also approved the creation of a similar and even more robust initiative for regional actions under the Department of Commerce's Economic Development Administration (Sec. 10621), having earmarked investments of US$10 billion over the next five years, of which US$500 million was already appropriated in the 2023 budget, as well as regional actions by the Department of Energy. See: https://www.eda.gov/funding/programs/regional-technology-and-innovation-hubs.

NSF has already announced funding of up to US$1 million for two years for the planning of new Engines and up to US$160 million for a timeframe of up to 10 years to support the development of 44 initiatives. By doing so, the goal is to form regional coalitions focused on use-inspired research which connect with the market and society to promote workforce development, stimulate the economy, and create new jobs.[20]

NSF & Semiconductors

The CHIPS and Science Act earmarked US$52.7 billion to increase semiconductor manufacturing capacity in the United States, with incentives to build, expand, and equip domestic manufacturing facilities and companies in the semiconductor supply chain. The Act also allocated funds for R&D activities (Sutter, Sargent, and Singh, 2023).

In this context, NSF has also expanded its action in support of semiconductor-related R&D activities by mobilizing its traditional directorates, but in association with its new Directorate for Technology, Innovation and Partnerships (TIP). The Future of the Semiconductors Program (FuSe) is a crosscutting action that mobilizes the support of the Directorates for Computer and Information Science and Engineering (CISE), Engineering (ENG), STEM Education (EDU), and Mathematical and Physical Sciences (MPS), together with TIP actions (Gianchandani, 2023).

FuSe's goal is to support fundamental research on materials, devices and systems that allow for the advancement of the new generation of semiconductors, taking into consideration: the integrated performance of these materials, devices, and systems; manufacturing capacity; recycling concerns; and environmental impact. Within the framework of FuSe, NSF announced relevant partnerships with Ericsson, IBM, Intel, and Samsung (industry partners), mobilizing US$50 million to support collaborative research projects on the new generation of semiconductors. It also announced public–private partnerships with the Semiconductor Research Corporation and Micron Technology to train skilled labor. Although these actions are small vis-à-vis the incentives granted to production and investment attraction efforts amounting to hundreds of billions of dollars, they are nonetheless a sign of the change

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20. The key technologies selected as the focus of these engines are artificial intelligence, semiconductors and high-performance computing, quantum science and engineering, advanced manufacturing, and clean energy. See: https://new.nsf.gov/funding/initiatives/regional-innovation-engines.

underway at NSF, exemplifying that it may be possible for the new Directorate to work in conjunction with other areas of the Foundation.

The challenge is not just in nearshoring by repatriating or encouraging production within the United States—perhaps the easiest task (Sutter, Sargent, and Singh, 2023)[21]—but rather in restoring leadership in semiconductor research, which the United States has also lost, investigating new techniques such as lithography or new materials (Kannan and Feldgoise, 2022).[22]

21. As these authors point out: "East Asia has also benefitted from decisions by U.S. industry to shift to a fabless model in which chips are designed internally and then produced by a contract manufacturer, generally outside the United States. The negotiation of lower tariffs through plurilateral trade deals on many inputs and finished products related to semiconductor and microelectronics production has also facilitated U.S. offshoring and the related expansion of the semiconductor industry in East Asia. Fabricators and packaging firms operating in East Asia have benefitted from the increased ease and cost effectiveness of moving wafers and chips across borders, in some cases numerous times, for design, production, testing, and packaging, as well as from easier and cheaper export of chips, including those embedded in finished products."

22. Aside from technology challenges, Kannan and Feldgoise (2022) point out other dilemmas: "How to align domestic and foreign semiconductor policy, how to ensure this industrial policy or its complementary initiatives make good on their promises to the domestic labor force, and how to navigate the political imperatives that will constrain future government action."

4. The Potential Impacts of the CHIPS and Science Act on Latin America

Semiconductors

Like other U.S. science and innovation policy reforms implemented in recent decades, the CHIPS and Science Act can be expected to have major implications for science and innovation policies worldwide. Initially, we can expect this to be reflected in the efforts of some countries to reduce their vulnerabilities in various value chains, especially in the health sector and in semiconductors. Undeniably, the possibilities of implementing policies for these sectors depend on preconditions that differ from country to country.

In the case of semiconductors—aside from in Asia, which is a separate issue—Europe has the best chance of designing active policies to maintain or increase its share of the global market (Sutters, Sargent, and Singh, 2023). The EU CHIPS Act organizes many of the European initiatives, with resources of US$43 billion to stimulate production and fund industry-related R&D activities. Its objective is to strengthen the continent's strategic autonomy, particularly in critical technologies, which implies building capacities that reverse the downward trajectory of the European share in this market. This action will depend heavily on cooperation with the United States, either because of the CHIPS and Science Act incentives, to avoid a race for subsidies, or even due to the important role that U.S. industries also play in the European market (Timmers, 2022). In Asia, countries such as Japan, Malaysia, and Singapore have investment attraction policies. South Korea and Taiwan offer even greater support for local industry, having the production capacity, and mastering many frontier technologies.

In the field of semiconductor production and research, although nearshoring and the so-called friendshoring[23] raise many expectations, with the possible exception of Costa Rica and Mexico, the outlook for Latin America generally is not promising. Mexico is already a producer of semiconductors and has unique potential, owing to human resource training, and the existence of programming and design centers in the country. Added to this is the fact that Mexico is the fourth largest exporter of automobiles, and the eighth largest producer of electronic goods, both of these sectors with a growing demand for chips. As Helfgott and Woo (2003) point out:

> "Historically, Latin America has been a peripheral player in the global semiconductor supply chain, but recent shortages have drawn attention to a potentially greater role for the region in the production of computer chips. The High-Level Economic Dialogue between the United States and Mexico, for example, now includes a semiconductor working group, where senior officials from both countries have discussed the possibility of semiconductor production in southern Mexico."

Costa Rica already has a unit dedicated to the final stages of chip production, and these activities are expected to grow in the coming years. An example is Intel's announcement that it will invest US$600 million in the assembly and testing of microchips, as well as in R&D activities. Other companies, such as Microsoft and Zollner, have also announced their intention to expand chip production and conduct R&D in the country (Helfgott and Woo, 2023).

Brazil is also likely to strive to take advantage of friendshoring by attracting investments, though it is far less able to compete in this market than Mexico and Costa Rica, despite in the past having implemented policies to stimulate the building of local capacity to design integrated circuits; it even has specific incentives for niches in the semiconductor sector, as well as special legislation for computer goods, with incentives for R&D activities. The problem, however, is that this legislation affects, in particular, finished telecommunications, consumer electronics, and information technology products. Also, the legislation, more than being an effective policy to stimulate local production of semiconductors, is a consequence of the attempt to balance production costs of the other Brazilian regions with the incentive regime in the Manaus Free Trade Zone.[24]

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23. Friendshoring is the act of manufacturing and sourcing from countries that are geopolitics allies.

24. Other possible investments in Latin America in lower value-added activities will stem from opportunities along the sector's supply chain, such as strategic minerals like rare earths, lithium and niobium.

Science and Innovation

The impact of the CHIPS and Science Act in the semiconductor sector in Latin America tends to be felt in the relatively short term, in a punctual way, and in only a handful of countries. However, the opposite appears to be true for the scientific part of the new Law. New policies and related institutional changes will be assimilated gradually and influence the design of science and innovation support agencies around the world, especially in the Americas, as occurred previously with changes in U.S. policies, thereby reinforcing the emphasis on the innovation of the last decade.

This influence promises to follow the course of other policy trends designed in developed countries and thereafter spreading to the wider world. Among such trends are: cooperation between actors in the innovation system, notably universities and companies and the emblematic Bayh-Dole Act; support for small innovative companies and startups; development of a venture capital market and a new wave of so-called mission-oriented research and policies, also included in the CHIPS and Science Act; and in the progress of the European innovation strategy, which is becoming the object of attention of many Latin American countries (Mazzucato, 2014; 2019).

This influence is expected to be greater in Latin American countries with larger, more advanced and robust research infrastructures, where the demands of the respective and influential academic communities are served and inspired by the U.S. model and the lasting legacy of Vannevar Bush. This is especially true for NSF actions, which have always vouched for basic and disinterested science, usually fostered according to the "investigator initiative" and with a management structure based on directorates or coordination units by areas of knowledge. This model prevailed for decades up until the creation of TIP, where the organization by areas of knowledge is maintained, but with the addition of a crosscutting action by the new directorate, focused on innovation.

The traditional NSF model was widely influential globally, especially for agencies with a greater focus on supporting scientific research. The influence in Latin America was very much in tune with the fact that funding for R&D—conducted primarily by universities—was mostly public. To date, investment levels and instruments used have been insufficient to induce a relevant change in industrial research in the region. In this context, U.S. influence

has gradually adapted to the relative weakness of national innovation systems, leading to increasingly broader policy agendas and agency structure (Dutrénit et al., 2021).[25]

Angelelli, Luna, and Suaznábar (2017) have indicated that in this context of weak innovation systems, Latin America's S&IT agencies engage in a wide range of activities:

> "(...) from the promotion of basic and applied research to innovation and entrepreneurship, thus interacting with a wide range of possible beneficiaries, from researchers and universities to companies and entrepreneurs, as well as a consortia of various actors."

This results in a mixed action, which aims both to upgrade companies in the economy, and promote the development of innovative technologies and new businesses. The institutionality of support for science and innovation in Latin America also has a fragmented design but different from the one referred to by Bonvillian (2014) in the U.S. case, where the institutions were differentiated by sectors (defense, energy, health, agriculture, and industry, inter alia). Here, although with some cases of sectoral focus, fragmentation was driven more by the client base: academia, higher education, industry, and small enterprises, inter alia.

In many Latin American countries, U.S. influence was at the core of national research and science councils, many of which were created in the immediate aftermath of World War II. In Brazil, aside from the national agencies, several regional research support agencies—the State Research Support Foundations—were inspired by the trajectory and design of NSF, particularly in areas where the academic community was stronger, such as the State of São Paulo.[26]

Over the decades and with the new challenges of industrialization and the innovation agenda, this institutionality has changed. The U.S. influence has been translated into policy, as there has never been a U.S. central agency focused on innovation per se, that would serve

25. This weakness has existed for decades and has worsened in some countries: "Since 2015, research intensity in Latin America has remained relatively low, with Brazil maintaining its lead for this indicator. Research intensity has recently dropped in Argentina, Brazil, and Mexico while rising, albeit modestly, in El Salvador, Paraguay, and Uruguay" (Dutrénit et al., 2021).

26. A folkloric testimony attesting to this influence was given by an important former scientific director of FAPESP. When FAPESP launched the São Paulo version of the Small Business Innovative Research (SBIR), which already existed at NSF for 20 years, it asked the advisory board to translate the full NSF program and said: if NSF does it, I will convince the Foundation's Board to do it too.

as an example.[27] The influence was through emphasis on commercialization of intellectual property, the role of technology transfer, the connection between actors and public–private partnerships, technological infrastructure, support for small innovative companies and technology-intensive startups, the strengthening of the venture capital industry, the creation of innovation environments, and certain sectoral agendas (agriculture, space, etc.).

As Cuello, Glennie, and Zohlo (2022) point out, to assess the impact of the CHIPS and Science Act requires the recognition that innovation agencies are gradually gaining prominence in Latin America, with diversification and sophistication in the mix of instruments they manage, and greater institutional and budgetary capacities. This is especially true in cases where policies relating to science, technology, and innovation are coordinated with the growth and productivity strategies of each country. The authors show that, for many reasons, the development of these agencies has not been homogeneous:

> "Some countries have opted for an integrated or dominant agency that covers policy instruments from basic science to innovation. Others have opted for dual models, where independent specialized agencies deal with science and advanced human capital, while other independent, specialized agencies focus on innovation and entrepreneurship."

In general, they identify that many that have been created recently; are focused on small enterprises, offering grants and support for early-stage innovations; and adopt a vision of Vannevar Bush's linear model of innovation, which is strongly criticized by Stokes. In their words:

> "This model (...) is biased toward more radical, disruptive, and novel innovations (...) the model misses the fact that most firms can gain substantial improvements in productivity by adopting knowledge and technologies that already exist. The traditional model helps increase inputs to innovation, but does not necessarily increase capabilities, or improve framework conditions for innovation, which are also essential."

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27. DARPA, while not exactly an innovation agency, could perhaps inspire reforms in the agencies' decision-making processes, with mechanisms for greater risk exposure and project portfolio management different from the investigator initiative approach. But the design of new U.S. agencies (ARPA-E and ARPA-H) and of the British ARIA was more influenced by DARPA than by Latin American policies.

The issue they address is the failure of these policies to help companies develop the necessary capabilities for carrying out incremental innovations, and thereby overcome the bias that innovation is mainly based on science, formal R&D and inventions. In their view, fostering R&D does not necessarily entail interrupting financing instruments; it is rather a matter of balancing policies, with equal emphasis on strengthening capacity-building in companies.

This point of view is not new and was one of the central ideas of the research coordinated by Cirera and Maloney (2017), who sought to depict what they call the paradox of innovation. In developing countries, although the expected returns on investment in innovation are extremely high, the investments themselves are low, owing to weak company management, and the absence of a broad set of complementarities, such as physical and human capital. Important in the authors' view is that innovation policies should consider this specificity in developing countries, where innovation would consist of marginal improvements in processes or products, and seldom involve research at the frontier. Thus, they suggest, the appropriate policy model to support innovation would be different from that of advanced countries, where it more commonly focuses on supporting R&D. They propose that the appropriate policy mix should consider the level of capabilities of firms and take progressive steps toward increased sophistication, in what they refer to as a "capabilities escalator." However, given the profound influence of the policies and institutional models of more developed countries, this, they say, is not always considered. The result would be failures that stem from the simple importation of practices that are not in tune with reality. This is the core message of their study; equating innovation policy with frontier science and technology policy will lead to frustration and waste if the size of the firm is neglected.

In other words, in many developing countries there is a tendency to attempt to create national innovation systems like those of more advanced countries, and to support more complex R&D projects and the development of innovative technologies. But this would be far from the real need of the industry, even though, they warn, there may be companies capable of conducting sophisticated R&D projects. Furthermore, this is exacerbated when countries mimic the organizational charts of advanced countries but fail to create institutions to solve a local problem. This message is highly relevant when assessing the impact of recent NSF reforms in Latin American countries. However, it begs the question as to whether mimicking these reforms is merely a repeat performance of the tendency to import organizational charts, which are out of line with the degree of sophistication of the economy (Cirera and Maloney, 2017).

5. Concluding remarks and an agenda of points of attention

The NSF reform undertaken by the CHIPS and Science Act has been the most important one of the past 30 years, incorporating the creation of the Directorate for Technology, Innovation and Partnership. It represents a significant advance in the design of U.S. science and innovation policies. Even though it does not address the concerns of many experts, establishing a specific agency focused on innovation is a relevant step in that direction.

A mapping of the main drivers of recent changes in the most important international science and innovation promotion agencies shows a clear effort to incorporate and emphasize the issue of innovation and an attempt to achieve a greater impact from research (Salles Filho et al., 2022).[28] To an extent, this follows the pattern of the reforms that began in the United States, first with the creation of DARPA, then with commercialization of technology in the 1980s, and the creation of ARPA-E, nearly two decades ago.

With adaptations to local contexts, these changes have reverberated worldwide. An interesting example is the recent creation of ARIA in the United Kingdom, aimed at stimulating bolder and more disruptive projects, and undeniably inspired by the DARPA model (Owen, 2021).[29]

There remain open issues for assessing the real success of this reform, such as the feasibility of a cultural change within NSF; the actual implementation of new budget proposals; the ability of the new directorate to work jointly with other NSF thematic directorates, and

28. The document analyzes the following drivers of these changes: strategic planning and prioritization, decision-making, research and innovation linkages, impact and impact evaluation; societal engagement, good research practices, and networks of international collaboration.

29. The DARPA model does not focus so much on applied technologies as opposed to basic research, but is, rather, an attempt to support bolder, higher-risk projects.

with all other research and innovation funding agencies in the United States; and, finally, the issue of how to reconcile the permanent dilemma between the allocation of funds for curiosity-based and use-inspired research.

However, over and above stimulating industrial policy actions that build upon the new context of international rivalry and the possibilities of 'friendshoring', the change will have impact. This impact will be greater in agencies more focused on supporting scientific research, in the style of NSF itself, such as national science councils and research support foundations, but it will also affect innovation agencies, lending them greater legitimacy in their respective scientific and technological communities.

The impact of the actions of the new directorate and their selected focus on the agenda of international agencies remains to be seen. This focus has two aspects: on one hand, the so-called critical technologies, and on the other, the selection of several national and global challenges for mission-oriented research, although this term is not used in the U.S. reform.

For decades, various countries, in particular the more developed ones, have designed programs for some of these technologies; the best example is the set of issues related to Artificial Intelligence. The selection made by the CHIPS and Science Act tends to further accelerate this race, which relies not only on public initiatives, but also on the increasingly relevant role of the private sector. The same is true for the so-called mission-oriented research.

The question for Latin American countries is how these reforms will impact national policies and the corresponding actions of their research promotion and innovation support agencies. It has usually taken a long time for U.S. reforms to be incorporated into Latin America's policy mix, such as SBIR-inspired actions to support innovative small enterprises.

The issue here is two-fold: on one hand, whether these reforms can inspire changes that emphasize innovation and the prioritization of actions for a selected range of technologies; and on the other, whether these changes can divert attention again to what Cirera and Maloney (2017) call organizational charts that are out of line with the degree of sophistication of the economy.

Emphasis on the first issue can assist policies, creating the opportunity for more selective actions. For decades, Latin American initiatives have sought to act on fronts identified as future-bearing technologies, but with a very wide range of initiatives not always compati-

ble with local capacities, or the respective public budgets. Prioritizing, therefore, can be a productive consequence of these reforms.

The second issue is more complex. It involves adjusting the policy mix to place more emphasis on technology diffusion actions. The relevance of these actions and the specificity of the institutions focused on this agenda have long been known, especially regarding small and medium-sized enterprises.

Pacheco (2020) points out the relevance of the discussion due to the inescapable tendency to emphasize the most spectacular advances in research and the potential of innovative technologies. However, the economic and social value of the latter only materializes if they can be expanded, diffused, and improved in use. As Shapira and Youtie (2017) put it:

> "Policy makers tend to acknowledge the importance of technology diffusion at a high level, but to overlook technology diffusion in the subsequent allocation of attention and resources."

It is worth remembering, however, that while the diffusion of existing technologies is relevant, it is also important to encourage R&D activities. This applies especially to middle-income economies and more complex industrial structures, which coexist with a high degree of productive heterogeneity, where large national and transnational companies—alongside technology-based startups—drive the increase in productivity and disseminate innovative technologies throughout the production activity. For these companies, R&D incentives are truly relevant and, as is widely known, bring with them much higher social returns than those that can be appropriated privately.

Some studies show that innovative technologies developed at the global frontier are spreading at an ever-faster pace across countries, but have slowed down considerably within each economy, and many technologies may remain untapped by a substantial proportion of companies. These studies also show that the leading companies in each country can play a truly relevant role in disseminating the use of innovative technologies to their supply chains and even to other companies. As Andrews, Criscuolo, and Gal (2015) state:

> "The productivity growth of laggard firms within a country is more strongly related to productivity developments of the most advanced domestic firms, as opposed to those (foreign firms) at the global frontier."

In other words:

> "New global frontier technologies do not immediately diffuse to all firms. Instead, they are first adopted by national frontier firms, and only diffuse to laggards once they are tested by the leaders and adapted to country- specific circumstances."

It is as if, in this case, especially for countries with more complex structures, there were actors on different rungs of the ladder.

These considerations can help Latin American agencies identify the best mix of policies to support science and innovation in each country. The pertinent issue is that they depend on the degree of sophistication of its productive apparatus, and on existing scientific and technological skills. There is no single answer, but there is no doubt that the innovation agenda is an essential part of national ST&I policies.

By examining U.S. policy reforms, it is possible to summarize the points that will be pertinent to Latin American innovation agencies in the coming years. This can facilitate the debate on the impact in the Latin American context and on which aspects deserve to be monitored and endorsed. They include the following aspects:

1. Critical technologies: The approach taken in the CHIPS & Science Act of selecting no more than ten critical technologies is a relevant indicator of the need to focus on a few key issues. Here it is clear that these choices must not only concentrate efforts on pre-defined topics, but that the choice itself must consider pre-existing scientific and technological capabilities and future challenges.
2. Mission-Driven Research: The introduction of five relevant topics associated with U.S. national challenges replaces an agenda that has influenced many agencies around the world. In many cases this has been referred to as mission-oriented research and is stimulated by local and global challenges, in some cases, associated with the sustainable development goals agenda. This already is, and will continue to be, a driver of change for the world's innovation agencies, and Latin American agencies could follow the organization of these actions by the United States and in Europe.
3. Balance between curiosity-driven research and use-inspired research: The example of the NSF reform points to the need to balance initiatives to support use-oriented research with those derived from the free choice of the academic community. This is a topic that divides opinions, especially in countries with more robust scientific

communities, often through confusing oriented research with basic research, and use-oriented research with applied research, or technological development. Here, this mix must be formulated, not only to address challenges, but also to stimulate the development of the new generation of scientists.

4. New innovation hubs: The agenda to support new innovation hubs (from NSF and DOC) poses a relevant question; if innovation becomes a determinant of economic growth productivity, actions are required to disseminate or generate new knowledge that opens up development possibilities for regions which are normally excluded from the benefits of previous cycles of technological progress.
5. Diversity and inclusion: Today, the agenda of specific actions for gender and race issues, as well as for a wide variety of minorities, is an inseparable part of the concerns of the best innovation agencies in the world. Besides meeting an equity imperative, it also seeks to incorporate new segments into the S&IT workforce, bolstering local capacities by mobilizing underrepresented groups in this workforce.
6. Partnerships between companies and research institutions: For decades, the agenda of collaboration between actors in innovation systems has been the keynote of many innovation policies (Bayh Dole Act, Engineering Research Centers, Small Business Technology Transfer, and Advanced Manufacturing Centers, inter alia). The ongoing reform adds new instruments to this agenda, especially in the dimension of the interface between science and industry, by establishing an NSF directorate to address issues that intersect with the agency's traditional areas of activity.
7. Innovation versus initiatives organized by areas of knowledge: The actions and internal structure of scientific research support agencies have traditionally been organized by directorates or managements, which in turn are arranged by areas of knowledge. This has been questioned under the growing complexity and synergy between different fields of knowledge, and now gains a new point of attention with the introduction in the main U.S. agency of support for basic research of a directorate that intersects with the directorates organized by areas of knowledge. This may stimulate new forms of action or explain the difficulty of implementing a deeper cultural change in these agencies.
8. Diffusion versus new knowledge: The importance of technology diffusion and the recognition that its implementation requires specialized institutions and increased attention from innovation agencies. This is true for well-known topics, such as lean manufacturing practices, as shown by the recent Brazilian experience, but it is also true for new issues, such as digital technologies and artificial intelligence, which will

be decisive for companies, and which often require incentives for the adoption of existing solutions which are not restricted to research based on new knowledge.

9. Investigator initiative, versus strategic choices: The option to focus on critical technologies and mission-oriented research actions, which are generally top-down actions, implies the need to also balance initiatives based on the researcher's freedom of initiative, versus actions determined by strategies established by the agencies' directorates or by other government agencies or even taken on by the government in coordination with the private sector, or with academia.
10. Diversification of instruments for a broad agenda of support for innovation: Traditional actions to support research revolve around, or focus on, the provision of public funds in the form of grants, or on actions to support collaboration between universities, institutes, and companies. But there is a clear need to mobilize new financial instruments to stimulate innovation and riskier R&D activities, whether in the form of guarantees, venture capital, hybrid finance, or other types of equity. This is a complex agenda that requires institutions which are much better equipped than traditional research promotion actions.

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