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Identifying Technological Trends and Promoting Strategies to Boost Innovation and Technology Transfer: A Case Study on the Patent Portfolio of Brazilian Public Research Institutions

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ABSTRACT

The development of innovative technologies represents a fundamental pillar for economic and social progress in countries, and understanding the opportunities for utilizing these technological solutions is a critical success factor. The dynamics of the technology transfer (TT) process are determined by the peculiarities of factors related to both the consumer market and the business environment in which scientific and technological institutions (STIs) operate. In the aerospace and defense sector, technologies have high dual-use potential and interest various industrial sectors. This manuscript explores emerging trends and the potential for TT of the intellectual property (IP) portfolio of these STIs across a diversified spectrum of significant technological areas in the industrial sectors. It is a case study applied to public STIs, seeking to understand the trajectories of technological development and anticipate their impact on the Brazilian productive sector. This focus is relevant as it addresses critical aspects affecting research, development, and innovation (RD&I) in public STIs, which are all essential to deciphering the complexities of the contemporary technological innovation ecosystem. This study offers valuable insights for researchers and managers of RD&I and TT, highlighting the critical role of technology in understanding the dynamics of innovation and managing of RD&I in the sector in focus.

Keywords: Intellectual property; Economic appropriability; Analysis of technological trends; Public institutions of science and technology; Brazilian aerospace and defense sector.

INTRODUCTION AND CONTEXTUALIZATION

The development of new and innovative technologies represents a fundamental pillar for the economic and social progress of countries (Fujino and Stal 2007; Levin et al. 1987; Lima *et al.* 2019). Supporting this development are the economic appropriations of technologies, which ensure that inventors and institutions have exclusive rights over their inventions (Encaoua *et al.* 2006).

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By protecting inventions, the aim is to create an environment conducive to technological development, where ideas can be developed and economically exploited without the risk of being improperly appropriated by others (Barbosa 2010). This stimulates investment in new research towards innovative solutions and creates a virtuous cycle of innovation and economic growth.

These rights are not just a recognition of the effort and investment in research and development (R&D), but also a crucial mechanism for business strategies in the pursuit of competitive advantages, for improving the quality of life of people and for driving economic growth (OECD 2004).

In the complex process of research, development, and innovation (RD&I), understanding the possible opportunities, both for future R&D activities in research centers and for the industrial sector interested in incorporating and modernizing their industrial processes, developing and exploiting new products within their corporate strategies is a critical success factor.

In public scientific and technological institutions (STIs), the integration between technological development, protection of intellectual property (IP), and its transfer to the industrial sectors is, therefore, a strategic vector for the sustainable economic and technological development of countries, given their political objectives of creation and institutional operation.

In this context, governments, research institutions, and the productive sector must work together to create RD&I policies and organizational structures that promote innovation, protect inventions, and facilitate the technology transfer (TT) process (Etzkowitz 2002).

This collaborative effort not only accelerates economic development, but also ensures that the benefits of innovation are shared across society, contributing to a more prosperous and sustainable future (Edquist 1997; Lundvall, 1992). Indeed, this guarantee is a principle of the Innovation Law Nº. 10.973/2004 (Brasil 2004).

It is known that the dynamics of the TT process are determined by the peculiarities of a set of factors related both to the market itself and to the business environment in which research centers operate (Bozeman 2000). In this scenario, the technological issue is just one side of the prism where economic appropriations are embedded.

In the aerospace and defense sector, technologies are typically cutting-edge, featuring complex customized products and systems. These technologies are engineering-intensive, high-performance, high-cost, and high-value-added, and are considered strategic by the producing nations and companies (Becz *et al.* 2010; Carvalho 2011; Schmidt 2011). These technologies have a high potential for dual use and are of interest to various industrial sectors.

The STIs that are the focus of this study are all located in São José dos Campos, state of São Paulo, a recognized Brazilian hub for aerospace and defense development: the Institute of Aeronautics and Space (IAE), the Institute for Advanced Studies (IEAv), and the Aeronautical Technology Institute (ITA). These public STIs perform teaching, research, and development activities to technologically support the needs of the agents in the innovation ecosystem and have robust competencies, derived from the high technical level of their professionals and diversified laboratory infrastructure, distributed in areas of knowledge essential for the aerospace and defense field. They execute a varied portfolio of RD&I projects in advanced technologies of manifest strategic importance for the country.

This manuscript reflects on the RD&I process in public technology-based STIs, considering the IP obtained by them, and explores emerging trends, knowledge gaps, the potential of TT from these IPs, and the dynamics of the innovation process in a diversified spectrum of industrial sectors. It focuses particularly focus on the areas of measurement instrumentation, testing, and navigation, among other significant technological sectors in which the STIs operate.

In doing so, the aim is not only to understand the trajectories of technological development, but also to anticipate the impacts of these trends on the economy (Campbell 1983; Kaminishi *et al.* 2014), on STIs, and on Brazilian society as a whole. This focus is relevant as it addresses critical aspects that affect RD&I, including IP management, TT management, economics, and project management, all essential for deciphering the complexities of the contemporary technological ecosystem. This holistic approach is reflected in the diversity of the industrial sectors analyzed, ranging from precision equipment manufacturing to software development and consultancy services.

Finally, this manuscript aims to contribute to the academic debate on the future of technological innovation in Brazilian public STIs, proposing future directions for research and practice. By mapping current and emerging trends, this study not only provides valuable insights for academics, developers, and policymakers in RD&I and TT, but also highlights the critical role of technology in shaping a sustainable and inclusive future. This represents a significant contribution to the understanding of innovation dynamics.

By offering a comprehensive and multidisciplinary analysis, it establishes an important milestone in the study of technologies developed in public STIs in the Brazilian aerospace and defense sector, outlining a promising path for future investigations in this vibrant and rapidly evolving field.

METHODS

The methodology adopted in this research was meticulously planned to address the complexity and diversity of data related to the innovation and technology development process, ensuring a comprehensive and in-depth analysis of trends and knowledge gaps in the fields studied. A case study methodology was applied in public STIs in the Brazilian aerospace and defense sector.

This work begins with the careful selection of sources, involving an extensive search in patent databases, both from Instituto Nacional de Propriedade Industrial (INPI) and similar bodies abroad.

Data collection presented a significant challenge, given the dispersed and often restricted nature of the necessary information. This multifaceted approach ensured the capture of a broad range of data relevant for analysis.

A patent research and intelligence application, PatSeer, from Gridlogics, was used to support the presented analysis. As disclosed by the company, for the industrial areas related to the technologies, the Statistical Classification of Economic Activities in the European Community (NACE) was used. Regarding the categorization of patents into technological domains and subdomains, the International Patent Classification (IPC) was used.

The identification, filtering, storage, and analysis of the data were conducted by the authors aiming to extract valuable insights about emerging trends and potential knowledge gaps.

To substantiate the analysis of the collected data, a systematic review of the established literature was carried out. Systematic review methods were employed to generate trends and descriptive models. This robust theoretical basis allowed for a deep interpretation of the data, contributing to the construction of a detailed situational awareness of the field studied.

The analysis focused on identifying significant trends, rather than presenting purely quantitative results, providing a richer understanding of the emerging patterns in the sector. Data triangulation played a crucial role in validating the findings of this research. Comparing results obtained in the case study strengthened the reliability of the insights generated, ensuring a holistic understanding of the investigated themes.

The research adopted a mixed-methodological approach (Creswell and Creswell 2021), utilizing extensive content analysis of documents and bibliographies, combined with qualitative techniques to demonstrate trends. This mixed approach allowed for a detailed exploration of the variables under study and the identification of significant associations between them.

Considered applied research, this approach aimed to generate practical knowledge to solve specific problems in the field of innovation and TT, using real and consolidated data. The applied nature of the research underscores its objective to contribute directly to innovation and technological development (Creswell and Creswell 2021; Gil 2010; Matias-Pereira 2019; Prodanov and Freitas 2013).

Finally, this research was structured to initially frame itself as an exploratory investigation, aiming to understand complex phenomena from a wide variety of sources. As the research progressed, it adopted a more descriptive character, establishing clear associations between the studied variables and outlining the current landscape of innovation and technologies in the focused STIs. This multifaceted methodology ensured a comprehensive and detailed analysis, contributing significantly to the field of study.

RESULTS AND DISCUSSION

To present the results of this research, it is important to highlight the context and direction that guided our study. As mentioned above, an IP research and intelligence application was used to collect data from patent databases, both at the INPI and at similar institutions abroad.

From this data collection, information was filtered on the industrial sectors associated with the IPs in the Scientific Technological Institutions IAE, IEAv, and ITA portfolios. This was done by taking into account the IPs obtained, those in active use, and those that have lost their exclusive exploitation rights due to their legal expiration date. The resulting information is presented in Figs. 1-6.

Measuring, testing, and navigation instruments; watches and clocks
Basic chemicals, fertilisers, nitrogen compounds, plastics and synthetic rubber in primary forms
Cement, lime and plaster
Metal forming machinery and machine tools
Other special purpose machinery
Communication equipment
Electronic components and boards
Optical instruments and photographic equipment
Forging, pressing, stamping and roll-forming of metal; powder metallurgy
Other transport equipment
Basic metals
General purpose machinery
Motor vehicles
Man-made fibers
Manufacturing N.E.C.
Medical and dental instruments and supplies
Computers and peripheral equipment
Other chemical products
Other general purpose machinery
Computer programming, consultancy and related activities
Construction of other civil engineering projects
Construction of utility projects
Irradiation, electromedical and electrotherapeutic equipment
Other manufacturing
Rubber and plastic products
Containers for storage or transport
Pesticides and others agrochemical products
Textiles

Source: Elaborated by the authors.

Figure 1. Industry – IAE and IEAv – All IP obtained.

Measuring, testing, and navigation instruments; watches and clocks
Basic chemicals, fertilisers, nitrogen compounds, plastics and synthetic rubber in primary forms
Cement, lime and plaster
Metal forming machinery and machine tools
Other special purpose machinery
Communication equipment
Electronic components and boards
Optical instruments and photographic equipment
Forging, pressing, stamping and roll-forming of metal; powder metallurgy
Other transport equipment
Basic metals
General purpose machinery
Motor vehicles
Man-made fibers
Manufacturing N.E.C.
Medical and dental instruments and supplies
Other general purpose machinery
Computers and peripheral equipment
Other chemical products
Computer programming, consultancy and related activities
Construction of other civil engineering projects
Construction of utility projects
Irradiation, electromedical and electrotherapeutic equipment
Pesticides and others agrochemical products
Textiles

Source: Elaborated by the authors.

Figure 2. Industry – IAE and IEAv – Active IPs.

This initial direction aimed not only to map the current state of the patent portfolio of these public STIs, but also to identify knowledge gaps and opportunities for future investigations. With this in mind, the following results offer significant insights into the nature and direction of innovation, reflecting the complexity and interconnectedness of this constantly evolving field.

It should be noted that these STIs are subordinate to the Department of Aerospace Science and Technology (DCTA), an agency of the Aeronautical Command. The IAE is tasked with developing projects and activities in aeronautics, space access, and defense. The IEAv is responsible for conducting applied research and experimental development with the future applications in aerospace technologies and systems. ITA is a university institution specializing in engineering education and research related to aerospace activities. Thus, ITA's IP portfolio contains technologies in various fields of knowledge, many originating from the teaching and research activities demanded by the companies that seek it for human resource (HR) training in *stricto sensu* courses.

Basic chemicals, fertilisers, nitrogen compounds, plastics and synthetic rubber in primary forms
Measuring, testing and navigation instruments; watches and clocks
Communication equipment
Cement, lime and plaster
Other special purpose machinery
Basic metals
Metal forming machinery and machine tools
Motor vehicles
Electronic components and boards
Forging, pressing, stamping and roll-forming of metal; powder metallurgy
Other manufacturing
Rubber and plastic products
Computers and peripheral equipment
Containers for storage or transport
General purpose machinery
Manufacturing N.E.C.
Medical and dental instruments and supplies
Optical instruments and photographic equipment
Other chemical products
Pesticides and other agrochemical products

Source: Elaborated by the authors.

Figure 3. Industry IAE and IEAv – DEAD (exclusive exploitation rights lost).

Based on the data presented in the Tables, some information can be inferred, which is important for mapping the technological roadmap and for strategic definition for technological innovation. The data collected, filtered, and analyzed allow a clear analysis of the status of various industries, categorized in different states of activity, namely: "ALL" (all cases), "ACTIVE" (active or ongoing cases), and "DEAD" (inactive or closed cases) for two distinct categories, "IAE and IEAv" and "ITA".

Regarding the most represented industries initially, it can be seen that in the categories IAE and IEAv and ITA, the industry of "Measuring, testing and navigation instruments; watches and clocks" appears as the most represented in terms of total and active cases. This suggests a strong concentration of activity or inventiveness in this specific segment, signaling an area of significant technological competence and potential development in the STIs. This trend not only highlights the existing capabilities in fields of high precision and advanced technology, but also points to strategic opportunities for growth and differentiation in the global scenario. Continuous and focused investments in R&D in this sector could lead to significant advances in measuring and navigation technologies, essential for various applications, from aviation and defense to space and maritime exploration, opening new horizons for the Brazilian industry.

Measuring, testing, and navigation instruments; watches and clocks
Metal forming machinery and machine tools
Other transport equipment
Basic chemicals, fertilisers, nitrogen compounds, plastics and synthetic rubber in primary forms
Other special purpose machinery
Man-made fibres
Medical and dental instruments and supplies
Optical instruments and photographic equipment
Communication equipment
Manufacturing N.E.C.
Other general purpose machinery
Cement, lime and plaster
Computer programming, consultancy and related activities
Computers and peripheral equipment
Construction of other civil engineering projects
Construction of utility projects
General purpose machinery
Irradiation, electromedical and electrotherapeutic equipment
Motor vehicles
Containers for storage or transport
Other manufaturing
Pesticides and other agrochemical products
Textiles

Source: Elaborated by the authors.

Table 4. Industry – ITA – All IPs obtained.

Moreover, the development of innovative technologies in this sector can serve as a catalyst for digital transformation in other areas, including precision agriculture, smart city management, and logistics. The integration of advanced measuring and navigation instruments with emerging technologies such as the internet of things (IoT), big data, and artificial intelligence (AI) can offer disruptive solutions that enhance efficiency, safety, and sustainability. By positioning themselves at the forefront of these technologies, the studied STIs can strengthen their competitive positions, attracting international investments and partnerships.

Furthermore, the ability to innovate and produce technologically in this segment also has significant implications for national industrial and defense policy. Technological sovereignty in precision instrumentation and navigation systems is vital for national security and strategic autonomy. By developing and controlling key technologies, the STIs can ensure greater independence in critical supply chains and strengthen their position in international negotiations and alliances. This also opens pathways for the country to lead in global technical standards and norms in new technological areas.

Measuring, testing, and navigation instruments; watches and clocks
Metal forming machinery and machine tools
Other transport equipment
Basic chemicals, fertilisers, nitrogen compounds, plastics and synthetic rubber in primary forms
Other special purpose machinery
Man-made fibres
Medical and dental instruments and supplies
Optical instruments and photographic equipment
Communication equipment
Manufacturing N.E.C.
Other general purpose machinery
Cement, lime and plaster
Computer programming, consultancy and related activities
Computers and peripheral equipment
Construction of other civil engineering projects
Construction of utility projects
General purpose machinery
Irradiation, electromedical and electrotherapeutic equipment
Motor vehicles
Textiles

Source: Elaborated by the authors.

Table 5. Industry – ITA – Active IPs.

Metal forming machinery and machine tools
Containers for storage or transport
Measuring, testing and navigation instruments, watches and clocks
Medical and dental instruments and supplies
Other manufacturing
Other special purpose machinery
Pesticides and other agrochemical products

Source: Elaborated by the authors.

Table 6. Industry ITA – DEAD (exclusive exploitation rights lost).

To capitalize on this presented trend, it is essential to create and enhance a robust innovative ecosystem involving not only ITA as an academic institution and the STIs IAE and IEAv, but also other universities, research centers, startups, and industries. This includes fostering interdisciplinary collaboration, offering and seeking incentives for R&D, and supporting, more than ever, the TT and commercialization of innovations. Public policies that promote education in science, technology, engineering, and mathematics (STEM), along with the encouragement of talent formation in emerging areas, will be crucial to sustaining growth and innovation.

In the long term, it is understood that strengthening the industry of "Measuring, testing and navigation instruments; watches and clocks" can be a strategic differentiator for the Brazilian nation, not only in terms of competitive advantage and economic development, but also as a pillar for security, diplomacy, and global technological leadership. The commitment to innovation in this sector reflects a future vision where the studied STIs not only keep up with global technological trends, but also actively contribute to shaping them, benefiting Brazilian society and the international community.

On the other hand, it can also be inferred from Tables 1 and 2 that there are industrial areas with a high rate of active cases (current), which show a high rate of active cases compared to the total, indicating a good sustainability index or a lower dropout rate. For example, in the category IAE and IEAv, "Measuring, testing and navigation instruments; watches and clocks" and "Cement, lime and plaster" show a significant number of active cases relative to the total, suggesting robustness and sustainability in these areas. This phenomenon suggests not only the vitality and continuity of innovative technologies but also a lower dropout rate by developers and researchers, which can be interpreted as a sign of potential commercial and strategic success if well managed and marketed. For the Brazilian economy, it is understood that these industrial areas represent critical areas of investment and development, capable of generating lasting competitive advantages and significantly contributing to sustainable growth.

If we consider the sector of "Measuring, testing and navigation instruments; watches and clocks", the high rate of active cases reflects the continuous demand for technological innovations and an enduring capacity to maintain relevance in the global market. This suggests that the STIs can establish themselves as centers of excellence in this niche, promoting advances in precision technology and navigation systems. The development of this industry is strategic, not only for the technology sector, but also for sectors dependent on advanced instrumentation, such as defense, aerospace, and agribusiness, enhancing the economic and technological impact in the country.

On the other hand, the industrial area of "Cement, lime and plaster" demonstrates remarkable resilience, with a high proportion of active cases. This points to a solid base of innovation in construction materials, crucial for the development of sustainable and energy-efficient infrastructure.

Investing in innovation in this industrial area can lead to significant advancements in civil construction, with the development of more sustainable, durable, and climate-adaptive materials. Such innovation can position the STIs as leaders in green construction technologies and sustainable infrastructure, aligned with global demands for carbon footprint reduction.

To capitalize on these opportunities, it is crucial that the STIs invest in mission-oriented innovation policies that promote research and development in these areas, including tax incentives, funding for R&D projects, and public-private partnerships. Collaboration among universities, research institutes, startups, and established companies will be crucial to accelerating innovation and the commercialization of emerging technologies. Moreover, strengthening programs of education and specialized technical training can ensure the availability of the necessary talent to drive these industries.

In the long term, the sustainable development of these industries has the potential to significantly transform the Brazilian economy, positioning the country as a leader in precision technologies and sustainable construction materials. This transformation would not only boost economic growth, but also contribute to addressing global challenges, such as climate change and sustainability. Therefore, continuous and strategic investment in these areas represents a promising path for national development, offering economic, social, and environmental benefits of far-reaching significance for public STIs.

Continuing a critical and strategic analysis of Tables 1 and 2, it is understood that there is a clear difference between the STIs of applied research (IAE and IEAv) and the educational and research STI (ITA), in the distribution of cases among the industrial areas. For example, in the area of "Metal forming machinery and machine tools" there is a greater emphasis in the ITA category than in IAE and IEAv, both in terms of total and active cases, highlighting distinct trends and innovation focuses within the Brazilian context of research and development. While IAE and IEAv may cover a broader range of innovative technologies, the prominence of the metal forming machinery and machine tools industry in the ITA category suggests an intensive focus on the evolution of advanced manufacturing technologies. This contrast points to a diversified innovative ecosystem, in which different industrial segments receive varied emphases, reflecting targeted technological development strategies.

The prominence of the industrial area of "Metal forming machinery and machine tools" in the ITA category indicates a significant concentration of efforts and resources on advancing manufacturing capabilities, essential for industrial competitiveness in a globalized economy. This suggests that ITA is positioning itself to strengthen its infrastructure and capabilities in the advanced manufacturing sector, a critical field for industrial innovation, productivity, and economic growth. Such a focus could facilitate the development of disruptive technologies, capable of transforming production processes, increasing efficiency, and reducing costs, thereby providing Brazilian industries with a competitive advantage on the international stage.

Moreover, this emphasis reflects the importance of innovation at the base of the production chain, which can have multiplier effects on other sectors, such as automotive, aerospace, and construction. This implies that investments and innovations in this area can not only improve the competitiveness of directly related industries, but also boost efficiency and innovation in sectors dependent on these fundamental technologies. Thus, this trend could be a crucial vector for economic development, promoting industrial diversification and specialization in high-tech niches.

To capitalize on this trend, it is essential that ITA continues to invest R&D, technical education, and the formation of strategic partnerships between the public sector, academic institutions, and the private sector. Stimulating cross-sector collaboration and investment in emerging technologies can accelerate the innovation process, with the technological transfer and commercialization of new solutions. Moreover, policies that encourage the adoption of advanced manufacturing practices and integration into global value chains can reinforce ITA's position as a hub of innovation and manufacturing.

On the other hand, when we examine the industrial sectors with a high rate of inactive cases (DEAD), we notice that some sectors show a high number of inactive cases, such as "Basic chemicals, fertilisers, nitrogen compounds, plastics and synthetic rubber in primary forms" as seen in the IAE and IEAv category. This could indicate specific sector challenges, such as high competition, regulatory changes, or innovations that make technologies or products obsolete, revealing important nuances about the challenges faced by this sector in the Brazilian context.

This situation may be emblematic of various market and innovation dynamics, including market saturation, increasing regulatory barriers, or the accelerated pace of technological replacement, which can lead to the obsolescence of existing products and technologies. Identifying these patterns is crucial for understanding the barriers to innovation and sustainable growth within specific sectors.

The high incidence of inactive cases in this sector suggests a need for continuous reevaluation and adaptation to market changes and regulatory demands. This could include investments in R&D to create new products and processes that are more environmentally sustainable, efficient, and in compliance with stricter regulations. Additionally, transitioning to bioplastics, organic fertilizers, and other sustainable alternatives could be a key strategy for revitalizing the sector, reducing the rate of inactivity by aligning with growing demands for greener and more responsible practices.

To address these challenges, it is crucial for companies and research institutions involved in these areas to prioritize open innovation and interdisciplinary collaboration. This may involve strategic partnerships with other universities, research centers, and tech startups, aiming to accelerate the development of new technologies and their rapid commercialization. International collaboration can also be a way to access new ideas, technologies, and markets, as well as share the risks and costs associated with innovation.

From a public or sectoral policy perspective, encouraging innovation in this sector may involve offering tax incentives, R&D grants, and support for forming innovation clusters that bring together businesses, academia, and government. Such policies can stimulate industrial modernization, sustainability, and international competitiveness. Implementing clear and stable regulatory frameworks is also crucial to providing a predictable business environment that favors long-term investments in innovation.

Finally, the high rate of inactive cases highlights an opportunity for the focused STIs to reposition themselves as leaders in sustainable innovation within this sector. By adopting strategies geared towards a circular economy, resource efficiency, and reducing the environmental footprint, the country cannot only overcome the specific challenges faced by this sector, but also set new standards for sustainability and technological innovation. This direction would not only strengthen the role of public STIs on the global scene as an innovative and responsible nation, but also contribute to sustainable economic development and long-term industrial resilience.

After analyzing the previous premises, clustering and trying to focus on clear trends for these authors, some general trends and insights can be presented in summary:

- There is considerable diversity in the industrial areas listed, ranging from measuring equipment to chemicals and machinery. This reflects the breadth of potential for innovation and industrial activity.
- The presence of categories such as "Computer programming, consultancy and related activities" suggests the increasing importance of the technology and consultancy services sector, although the total number of cases is relatively low.
- Industrial areas with few cases, such as "Textiles" and "Pesticides and other agrochemical products", may represent specific niches or areas with higher barriers to entry or regulation.

These trends are quite enlightening, allowing for a better analysis of the current situation and promoting R&D policies for the coming years, taking advantage of opportunities and acquired competencies.

CONCLUSIONS

In light of the data and insights presented in this study, it is crucial to reflect on the trends and gaps identified throughout the research process and on the management of the technological innovation process and R&D management. These processes aim to promote technological transfer to the Brazilian productive sector.

A detailed analysis of trends and dynamics in the areas of innovation and technological development in various industrial areas allows us to infer that these trends extend beyond mere technological progress, pointing to significant transformations in the economic and social scenario.

This summary seeks to consolidate the main findings, discuss their relevance to the field of study, and suggest directions for the strategic management of technological innovation and future research and development. This conclusion not only encapsulates the results of our study, but also highlights the vital role of technological innovation in shaping the future of industries and society as a whole.

Thus, an analysis of the general trends and insights inferred from the data obtained from the patent portfolios of the public STIs studied, as set out in the Tables presented, reveals a varied innovative potential with significant implications for the technological and economic future of the Brazilian productive sector. The diversity of industrial areas, ranging from measuring equipment to chemicals and machinery, underlines the wide range of possibilities for innovation and industrial activity that these STIs offer the sector. This variety not only reflects the opportunities for development and specialization in multiple sectors, but also highlights the technological complexity of the aerospace and defense sector's innovation ecosystem.

The prevalence of categories such as "Computer programming, consultancy and related activities" indicates the growing importance of the technology and consulting services sector. While the total number of cases is lower compared to other sectors, this suggests an emerging focus on information technology and digital services, areas recognized globally for their disruptive potential and ability to accelerate digital transformation across industries. The public STIs under study have the potential to establish themselves as leaders in R&D and technological innovation within the broader technological innovation ecosystem in Brazil and even in Latin America. This would be facilitated by their technology talent base and the growing digital infrastructure available.

Conversely, industrial sectors with few cases, such as "Textiles" and "Pesticides and other agrochemical products," may indicate specific niches or areas that face higher barriers to entry and stricter regulation. These sectors present opportunities for targeted innovation and the development of sustainable and environmentally friendly technologies that can meet global demands for cleaner and more efficient production practices. Investment in R&D in these areas can position STIs as leaders in sustainability and green technologies.

To capitalize on these opportunities, it is crucial that these STIs strengthen the innovation ecosystem in which they operate through proactive action via strategic management of the technological innovation process, including R&D management focused on the needs and interests of the agents in this ecosystem and effective management of the transfer of technological solutions to the Brazilian productive sector.

It is similarly crucial that they actively engage in the formulation of mission-oriented innovation policies that prioritize STEM, technological innovation management, R&D incentives, and collaboration between universities, research institutes, and industry. The development of international partnerships represents another vital factor in this strategy to reinforce the ecosystem, facilitating access to global markets and collaboration on cutting-edge research projects.

CONFLICT OF INTEREST

Nothing to declare.

AUTHORS' CONTRIBUTION

Conceptualization: Brandão Neto N; **Writing – Original Draft:** Brandão Neto N and Faria LA; **Supervision and Analysis:** Melo FCL and Faria LA; **Validation and Review:** Melo FCL; **Final approval:** Brandão Neto N.

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All dataset were generated or analyzed in the current study.

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