Patent Trends Analysis as a Basis for Innovation Strategies

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Abstract

The analysis of patent trends reveals significant patterns that have the potential to drive technological advancements in specific domains, particularly by identifying emerging areas and research gaps. This study examines how the economic appropriation of research and development outcomes mirrors the dynamics of the innovation process and informs strategic planning, policy formulation, and innovation management. By conducting a detailed analysis of the economic appropriations made by public science and technology institutions within Brazil's aerospace and defense sectors, we identify how these trends can inform proactive approaches to technological innovation. The institutions studied exhibit research and development and innovation dynamics that are finely tuned to the specific needs and trends of their technological fields, illustrating the increasing diversity of research and development interests and the complexity of the innovation ecosystems in which they operate. Ultimately, the success of innovation policies and strategies hinges on the ability to anticipate technological trends, strategically invest in high-potential areas, and efficiently transfer technologies to the productive sector. This ensures that institutions are well-positioned to respond quickly and effectively to technological changes and market opportunities, fostering sustainable development and technological progress.

Keywords: innovation development; innovation management; patenting; R&D management; R&D&I policies; technological change; Brazil

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Introduction and Contextualization

The intersection of technological innovation, Research, Development and Innovation (R&D&I) policies, and development strategies has become increasingly critical in the global landscape. As economies and societies face complex challenges, from economic sustainability to industrial competitiveness, the need for an integrated and strategic approach to innovation and technological development becomes imperative (Fagerberg et al., 2009; Mazzucato, 2013; Etzkowitz, Zhou, 2018). The distinction between R&D Management and R&D&I Policies is essential for understanding how innovation is managed and promoted at different levels. While R&D management focuses on the internal organization of projects and the operational efficiency of research and development within institutions, R&D&I policies encompass the regulatory and strategic instruments formulated to promote and guide innovation in key sectors. The interdependence between these two levels is evident: R&D managers operate within a normative ecosystem established by public policies, and these policies, in turn, are shaped by the needs and challenges identified in management practices. This differentiation allows for a more structured approach to analyzing innovation strategies, preventing conceptual misunderstandings between the roles of organizational managers and institutional policymakers.

This focus seems to be relevant as it addresses critical aspects of R&D management and technological innovation management in public Scientific and Technological Institutions (STIs), which are oriented toward expanding the technological capabilities of strategic sectors such as aerospace and defense, with the development of technologies that have the potential to be utilized by a wide range of industries. The complex innovation ecosystem encompasses the intricate interactions between patenting trends, institutional research activities, and national innovation policies. In the context of this study, it refers to how technological development is influenced by the interplay of scientific research, intellectual property management, and strategic policy-making. The aeronautics institutes analyzed operate within this ecosystem, where patenting is not just a measure of scientific output but also a reflection of broader strategic priorities in research and development. Understanding this complexity is essential for aligning innovation policies with institutional capabilities and market opportunities.

This work aims to offer critical insights for R&D&I policymakers, R&D managers, researchers, and innovation strategists, highlighting the importance of well-founded innovation policies and strategies that promote R&D in emerging and strategic areas. We will examine how focusing on specific technologies, such as microstructures and nanotechnology, semiconductors, and electrical engineering, as well as the commitment to R&D&I in fundamental technological domains, reflects global needs and demands for sustainability-conscious solutions. Furthermore, we will discuss how identifying strategic areas for investment and exploring opportunities for technology transfer can serve as catalysts for technological advancement and Brazilian economic development.

The statistics and dynamics of patenting is considered to be one of the key indicators of innovation activity. In this context, this article explores how patenting activities reflect the dynamics of the innovation process and how this information can guide strategic planning in Research and Development (R&D), as well as the formulation of R&D&I policies and strategies for innovation management. Thus, this article interprets these trends and identifies opportunities to align R&D strategies, R&D&I policies, and technology transfer strategies for the Brazilian productive sector.

Over the past two decades, the analysis of patenting trends at leading research institutions, such as those of the Department of Aerospace Science and Technology (DCTA), has revealed significant patterns of innovation potential. These patterns not only indicate technological domains with the capacity to drive significant advances in technological development but also highlight emerging research areas and existing gaps. Through a meticulous analysis of patenting and innovation activities within the STIs of the DCTA (Institute of Aeronautics and Space - IAE, Institute for Advanced Studies - IEAv, and Aeronautics Institute of Technology - ITA), we explore how these trends can reveal insights and guide efforts toward a proactive role in the technological innovation process.

Materials and Methods

The methodology employed in the present study reflects a comprehensive and meticulous effort to capture and analyze how the economic appropriability of R&D outcomes generated by the STIs IAE, IEAv, and ITA can produce economically relevant results, thereby feeding back into the R&D&I process. This effort also aims to provide insights for the formulation of strategic planning in R&D, as well as the development of R&D&I policies and innovation management strategies.

We applied an exploratory and descriptive research methodology (Gil, 2010; Prodanov, Freitas, 2013; Matias-Pereira, 2019; Creswell, Creswell, 2009) to establish associations among various variables based on data collected from multiple sources. We adopted an integrated approach, combining data collection methods, bibliographic analysis, and data analysis to ensure the robustness and validity of the findings. This holistic and integrated methodology ensured the generation of valuable insights for the formulation of effective innovation strategies and public policies in response to patenting trends.

Initially, the selection of sources formed the cornerstone of our research strategy, involving a case study in public STIs that are recognized as highly relevant in the research and development of technologies for strategic technological sectors essential for Brazilian economic and social development.

The PatSeer® IP research and intelligence application, developed by GridLogics, was used as the primary data collection tool from patent databases, including those filed with the National Institute of Industrial Property (INPI) and similar agencies abroad. The International Patent Classification (IPC) system was used to categorize the presented technological domains and subdomains.

The literature analysis involved a careful review and the use
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of established literature to support our data analysis. Our approach to data analysis was primarily qualitative, aiming to identify significant trends in relation to the adopted theoretical framework.

We opted for a qualitative representation of the obtained results, prioritizing the identification of patterns and trends over exact quantifications in order to capture the essence of the observed R&D and innovation processes.

Finally, the study can be classified as a clear example of applied research, given its intent to generate practical knowledge for solving specific problems, as the driving force behind technological innovation management studies is practice (Dodgson et al., 2014).

The validation of findings was achieved through data triangulation, a methodological strategy that involved comparing results obtained from different sources. This process strengthened the credibility and reliability of our conclusions.

Results and Discussion

The innovation dynamic requires both the formulation of R&D&I policies, which define incentives, regulations, and strategic priorities, and R&D management, which implements and operationalizes research and development strategies within institutions and companies. The relationship between these dimensions is not exclusive but complementary: policies establish broad directions and structure favorable environments for innovation, while R&D management translates these directions into concrete practices, projects, and applicable technologies. Ignoring this distinction would lead to a limited approach to innovation since the governance of research and development demands both political orientation and managerial competence.

Furthermore, while R&D management involves decision-making at the organizational and microeconomic levels, R&D&I policies operate on a broader scale, creating the institutional foundations necessary for innovation to thrive. The analytical separation of these dimensions enables a more refined study of innovation strategies, highlighting the interactions between the agents who formulate guidelines and those who execute innovative projects.

Innovation does not occur in isolation. It is embedded in a complex ecosystem where scientific research, patenting activities, institutional strategies, and policy frameworks interact dynamically. The aeronautics institutes analyzed in this study (IAE, IEAv, and ITA) contribute to this ecosystem through their specialized research domains, while their patenting efforts indicate areas of technological progress. At the same time, external factors such as government policies, funding mechanisms, and industry collaborations shape the direction of innovation, reinforcing the interconnected nature of technological advancement.

Recognizing this complexity allows for a more strategic approach to R&D&I, where technological foresight, institutional research capabilities, and economic appropriability must be considered together. By analyzing patenting trends and institutional roles within this ecosystem, we provide insights into how innovation strategies can be optimized to foster technological progress and economic impact.

The strategic management of R&D&I is a dynamic process that continuously evolves in response to technological advancements, policy interventions, and market demands. The institutions analyzed in this study operate within an adaptive framework where research priorities, collaboration models, and innovation strategies undergo constant refinement to maximize impact and relevance.

A key transformation in R&D management is the increasing integration of foresight methodologies, allowing institutions to anticipate emerging technological domains and strategically allocate resources toward high-potential research areas. This shift is evident in the evolution of research portfolios, where interdisciplinary approaches — combining materials science, nanotechnology, and electrical engineering — have gained prominence in recent years.

Similarly, innovation management has undergone significant transformation, moving from a closed model of internal development to a networked approach that emphasizes technology transfer, open innovation, and industry-academia partnerships. The increasing engagement with external stakeholders, including private-sector collaborators and international research networks, has facilitated a more agile and responsive innovation ecosystem.

Moreover, policy-driven shifts in STI governance have played a pivotal role in reshaping R&D&I strategies. The emphasis on sustainability, digital transformation, and dual-use technologies (civilian and defense applications) has led to new funding models, regulatory incentives, and collaborative platforms that encourage institutions to align their research agendas with broader economic and societal priorities.

These transformations illustrate that R&D management and innovation management are not static disciplines but rather evolving strategic systems that continuously adapt to internal and external drivers. A purely quantitative assessment of patenting trends, while valuable, does not fully capture the complexity of these strategic shifts. By incorporating these qualitative insights, we highlight how institutional governance, strategic foresight, and policy frameworks collectively shape the trajectory of research and innovation.

The relationship between R&D, innovation, and patenting is not linear but interactive, meaning that research outputs do not simply lead to patents—instead, patenting trends influence research directions and innovation policies in a continuous feedback loop. This interaction is evident in the patenting dynamics presented in Tables 1 and 2, which reveal:

- Sustained patenting activity in core technological domains such as materials and metallurgy, indicating strong institutional focus and long-term research investment in these areas. These domains benefit from continuous advancements, incremental improvements, and direct alignment with industry needs.
- More intermittent patenting activity in areas such as semiconductors and telecommunications, which suggests a higher dependence on policy incentives, funding availability, and interdisciplinary collaboration.
- Cross-sector influence, where advancements in one technological domain (e.g., optics) lead to spillover effects in other areas (e.g., instrumentation and measurement technologies). This demonstrates the systemic nature of innovation, where breakthroughs in fundamental research often trigger secondary waves of innovation across multiple disciplines.

The analysis of technological trends through patents is an effective and strategic mechanism for use in institutional S&T policies and for guiding innovation process strategies, including R&D management, economic appropriability, and technology transfer to the productive sector. (Campbell, 1983; Kaminishi et al., 2014; Niemann et al., 2017; Kim, Bae, 2017).

IIn public technology-based STIs such as IAE, IEAv, and ITA, R&D&I activities must be oriented toward meeting the demands of an innovation ecosystem that regularly faces the need to incorporate new technologies into its portfolio to remain competitive and active on a complex market, characterized by engineering-intensive, high-performance products with high cost and added value, as well as a high spin-off potential (Becz et al., 2010).

It is important to emphasize that the primary discussion on the strategic management of technological innovation in public STIs goes far beyond merely protecting inventions, as Intellectual Property (IP) should not be viewed as an end in itself but rather as part of the strategic management of the outcomes obtained in R&D&I. In this process of managing technological innovation, it is necessary to keep in mind that innovation depends on the particularities of technology and the market (Tidd et al., 2001).

Another key point is that R&D&I management is not an isolated activity with the sole purpose of managing projects and delivering research results; on the contrary, research and development management must be understood and approached from a systemic and interactive perspective (Rothwell, 1994; PMI, 2021).

This study adopts a systematic and interactive approach to analyzing research, development, and innovation trends. The systematic component involves a structured assessment of patent data, identifying key technological domains, patenting intensity over time, and potential areas for technology transfer. This approach allows us to map the evolution of innovation activities and their alignment with institutional and national priorities.

Simultaneously, the interactive component considers the bidirectional influence between patenting, research management, and innovation strategies. Instead of viewing patenting as merely an outcome of R&D, we analyze how patent trends feed back into research prioritization and innovation management frameworks. Through an extensive search of the patent databases of the STIs in focus, both from the National Institute of Industrial Property (INPI) and similar agencies abroad, extracted using the PatSeer® application and meticulously compiled into tables, we explore the evolution and impact of the conducted research, reflecting on the significant role that the DCTA STIs play in promoting technological innovation. This analysis aims not only to recognize the contribution of these entities to science and technology but also to understand how they shape technological trends and open avenues for new opportunities in technology transfer and industrial development.

The decision was made to separate the technological domains developed by IAE and IEAv from those of ITA. This separation is due to institutional characteristics. IAE is responsible for developing R&D projects and activities in aeronautics, space access, and defense, while IEAv is responsible for applied research and experimental development aimed at future applications in aerospace technologies and systems. ITA, on the other hand, is a higher education institution specializing in engineering education and research related to aerospace activities.

Thus, ITA's IP portfolio contains technologies in diverse fields of knowledge, many of which originate from teaching and research activities requested by companies seeking to train human resources in stricto sensu graduate programs, a trend that does not occur in the other STIs analyzed.

Tables 1 and 2 provide consolidated matrices of annual publications by technological domain for active patents associated with both DCTA's STIs (IAE and IEAv) and ITA, detailing patenting activity across different areas of technology over time. Some insights are extremely relevant regarding the potential for technology transfer, innovation, and its impact on the industry and the generation of profitable businesses.

The data consolidated in Table 1 (IAE and IEAv) allows for a detailed analysis of the trends in technological advances in the domains of "Materials" and "Metallurgy," highlighting a consistent pattern of patenting activities extending from 2006 to 2023. This continuity in patenting suggests a sustained commitment to research and development (R&D) in these fields, indicating several important trends in technologies with the potential to generate innovations.

Considering R&D in Materials, it is evident that this is crucial for the advancement of various technologies and industries, including electronics, automotive, aerospace, and healthcare. Advanced materials, such as nanomaterials, biomaterials, and new polymers, are at the forefront of research and development, offering enhanced properties like increased strength, lightweight, and specific functionalities, such as self-healing and stimulus responsiveness.

In the case of nanomaterials and composites, global research has been intense, focusing on the development of materials with unique properties for use in electronics, catalysts, and construction materials, which may indicate a prioritization wave for DCTA's STIs, leveraging their acquired expertise and established competence. The manipulation of materials on a nanometric scale enables the creation of structures with innovative physical, chemical, and biological properties. Similarly, this established competence can be leveraged to focus on sustainable materials, as sustainability has become a growing area of global focus, with research directed towards developing eco-friendly, recyclable, or biodegradable materials, as well as manufacturing processes that reduce waste and energy consumption. For this, government and private funding and incentives abound, which can favor the R&D sector of the DCTA.

Likewise, delving into another area highlighted in Table 1 of the STIs IAE and IEAv, patentability in Metallurgy emerges as a vital field for innovation, especially with the growing demand for materials that withstand extreme conditions and are produced more sustainably.

The development of Advanced Alloys, capable of operating at high temperatures and resisting corrosion, is fundamental for applications in extreme environments, such as aviation, hypersonics, and energy. Similarly, exploring what is known as Powder Metallurgy is essential, allowing for the production of materials with specific properties unattainable by conventional casting methods, crucial for manufacturing complex components used in various industries.

Finally, when it comes to recycling and sustainability, metallurgical processes can also include more efficient and environmentally friendly aspects. Thus, patenting in the areas of Materials and Metallurgy reflects a continuous pursuit of R&D&I that not only advances the state of the art in terms of material properties and functionalities but also addresses global challenges such as sustainability and energy efficiency, following current trends. These trends underline the importance of a multidisciplinary approach to research and development, integrating knowledge from chemistry, physics, biology, and engineering to tackle current and future challenges.

On the other hand, Table 2, which refers to ITA, clearly highlights technological domains such as "Instruments," "Mechanical Engineering," "Chemistry," and "Electrical Engineering," among others. This diversity of fields reflects a multifaceted approach to research and development, with Mechanical Engineering and Instruments showing the highest number of activities over the years, indicating a strong area of expertise and ongoing R&D&I.

The consistent presence of activities in these areas over the years demonstrates not only ITA's ability to maintain vigorous and relevant research but also its ability to adapt to new trends and demands on the technological market. This strategic focus on key areas such as Mechanical Engineering and

Table 1. **Status of Active Intellectual Properties of DCTA's STIs (IAE and IEAv)**

Tech Sub Domain	Publication year																		
	Total	**2002**	**2006**	**2007**	**2008**	**2009**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Materials	20		X	X	X	X		X	X			X	X	X	X		X	X	X
Metallurgy	20		X	X	X	X		X	X			X	X	X	X		X	X	X
Measurement	9				X	X	X				X	X		X	X	X			
Coating	6		X				X						X	X		X			
Surface technology	6		X				X						X	X		X			
Other special machines	4	X						X		X						X			
Engines	3										X					X	X		
Optics	3														X			X	X
Pumps	3										X					X	X		
Turbines	3										X					X	X		
Audio-visual technology	2	X										X							
Machine tools	2														X				X
Macromolecular chemistry	2												X				X		
Micro-structural and nano-technology	2								X								X		
Polymers	2												X				X		
Semiconductors	2												X			X			
Telecommunications	2	X										X							
Textile and paper machines	1					X													

**Note:* The totals may include multiple technological domains classified according to the International Patent Classification (IPC).

Source: authors.

Table 2. **Status of Active Intellectual Properties of DCTA / ITA**

Tech Sub Domain	Publication year															
	Total	**2008**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Instruments	25	X	X	X		X		X	X	X	X	X	X	X	X	X
Mechanical engineering	18	X			X	X		X	X	X		X	X	X	X	
Chemistry	12		X		X	X			X			X	X		X	
Electrical engineering	5		X									X		X		X
Other fields	5		X		X		X					X	X			

**Note*: The totals may include multiple technological domains classified according to the International Patent Classification (IPC).

Source: authors.

Instruments suggests a solid foundation for industrial collaboration and technology transfer, positioning ITA among the leaders in research and development in these areas. The diversification of technological domains also indicates a comprehensive approach to tackling complex global challenges, preparing ITA to significantly contribute to the technological innovation processes on the global stage.

Regarding Mechanical Engineering and Instruments specifically, the emphasis on these areas reveals robust expertise and continuous contributions to technological advancement. Mechanical Engineering, with its vast applicability - from the development of complex systems to the optimization of manufacturing processes - serves as a fundamental pillar for progress in various industrial sectors. R&D&I in this domain often translates into significant improvements in the efficiency, durability, and performance of machines and equipment, directly impacting industrial competitiveness.

On the other hand, the "Instruments" area reflects advances in measurement and control technologies, fundamental for scientific research, the manufacturing industry, and the service sector. The ability to measure accurately and control processes is vital for executing activities in areas such as aerospace, defense, healthcare, and energy, areas where ITA increasingly aims to establish itself as a reference for Brazil and the world. ITA's continued focus in this domain suggests proficiency in developing technologies that not only elevate the standard of experimental research but also strengthen the technological infrastructure necessary for R&D&I. Moreover, both Chemistry and Electrical Engineering are also highlighted in Table 2, revealing a diversification strategy aimed at addressing interdisciplinary challenges and exploring new scientific frontiers. Chemistry, especially in the era of green technologies and advanced materials, is a field rich in potential for innovations that promote sustainability and new material functionalities. Electrical Engineering, in turn, with its central role in the development of electronic systems, telecommunications, and information technologies, is fundamental for digitization and connectivity.

Finally, ITA's excellence in Industrial Collaboration and Technology Transfer not only ensures its leadership position in research and development but also establishes a solid foundation for proactive action and technology transfer. The ability to generate technologies applicable across multiple sectors positions ITA as a valuable partner for companies seeking advanced technological solutions, promoting economic development and responding to the demands of an increasingly technology-driven global market.

Continuing the analysis of Tables 1 and 2, we turn to another relevant trend that can be observed, namely the "Periods of High Patenting Activity" and consequently the "R&D&I Cycles."

In a more detailed analysis of the "Periods of High Patenting Activity," Table 1 (IAE and IEAv) shows a diverse distribution of patenting activities over the years across various technological areas, such as Materials, Metallurgy, and Measurement, among others. On the other hand, areas like Coating and Surface Technology show concentrated patenting activity between 2012 and 2023, indicating a significant focus on R&D&I related to these fields in the recent period. This may reflect an increased demand for new materials and surface technologies with enhanced properties for various industrial applications. Meanwhile, technologies such as Optics and Semiconductors also demonstrate consistency in patenting activity, suggesting ongoing development and interest in these sectors.

Considering Table 2 (ITA), one observes patenting activity in broader technological domains, such as Instruments, Mechanical Engineering, and Electrical Engineering, with consistent patenting activity in Instruments and Mechanical Engineering throughout the covered period, with peaks of activity in certain years. This suggests continuous investment in seeking innovations in these areas, possibly driven by technological advances and the need for more efficient and precise solutions. The area of Electrical Engineering shows a growing trend in patenting activity, especially notable from 2010 onward, reflecting the expansion of electrical and electronic innovations in response to the increasing demand for more advanced and sustainable technology.

Innovation and patenting activity do not occur in a linear progression; instead, they follow distinct R&D&I cycles, characterized by fluctuating periods of high and low innovation intensity. These cycles are influenced by a combination of technological maturity, institutional priorities, funding structures, and market readiness.

From the patenting trends observed in Tables 1 and 2, we identify three key factors shaping these cycles:

- Sustained research fields (e.g., materials and metallurgy) exhibit longer, more stable cycles, where innovation is driven by incremental advancements and steady funding.
- Disruptive and policy-sensitive fields (e.g., semiconductors, telecommunications, and optics) demonstrate shorter, high-intensity cycles, often triggered by regulatory incentives, breakthrough discoveries, or shifts in industrial demand.
- Cross-disciplinary fields (e.g., instrumentation and mechanical engineering) show intermittent cycles, where patenting surges occur when interdisciplinary innovations create new technological applications.

Understanding these cyclical dynamics is critical for strategic R&D&I management, as it enables institutions to anticipate and leverage periods of high innovation activity, aligning investments and research efforts with emerging technological opportunities. On this basis, they identify optimal timing for technology transfer and commercialization, ensuring that patented innovations reach the market at peak relevance. Finally, there are emerging opportunities to adapt institutional strategies based on cycle length and intensity, balancing investments between long-term foundational research and short-term disruptive innovation.

By integrating these insights into strategic innovation management, organizations can proactively navigate technology life cycles, enhance resource allocation, and strengthen institutional competitiveness in an evolving R&D ecosystem.

On the other hand, through a more detailed analysis of the "R&D&I Cycles," Table 1 (DCTA) presents continuous innovation and persistent interest in areas such as Semiconductors and Telecommunications, reflecting rapid innovation cycles where technology constantly evolves to meet new market demands. In contrast, areas with less patenting activity, such as Engines and Pumps, may indicate longer innovation cycles or a period of technological maturation, where disruptive innovations are less frequent but potentially more impactful when they occur.

Still in the "R&D&I Cycles", Table 2 (ITA) shows consistent activity in fields like Instruments and Mechanical Engineering, suggesting relatively stable R&D&I cycles, with incremental improvements being regularly introduced. This stability can be attributed to the fundamental nature of these technologies in a wide range of industrial and commercial applications. In contrast, the observed increase in patenting activity in Electrical Engineering may indicate a period of accelerated innovation in this field, possibly in response to advances in related technologies, such as renewable energy, consumer electronics, and communication systems, which are increasingly prominent on the global stage.

Moving on to some additional points that Tables 1 and 2 present in a very relevant way, we can clearly address "Research Gaps" and "Areas of Growing Interest".

In "Research Gaps", Table 1 (DCTA) suggests that some technological areas, such as Engines, Pumps, and Textile and Paper Machines, have relatively low or sporadic patenting activity over the years. This could indicate research gaps or opportunities for innovation and development in these areas.

The lack of recent patents in these categories suggests that there may be unresolved challenges or potential for new discoveries. The limited patenting activity in Audiovisual Technology also highlights a possible research gap, suggesting an opportunity for disruptive innovations that could transform this industry.

On the other hand, when looking at Table 2 (ITA), although it shows a broader distribution of patenting activities across technological domains, areas like Chemistry and Other Fields show lower patenting activity. This may indicate potential research gaps or areas that could benefit from renewed focus, especially considering the fundamental role of chemistry in emerging technologies and sustainability.

The lower number of patents in specific years for Electrical Engineering and Mechanical Engineering also suggests that there may be opportunities for exploration and additional R&D&I projects, especially in subdomains that have not been widely explored.

Once the "Research Gaps" are understood, the next important step is to analyze those "Areas of Growing Interest", which, based on Table 1 (IAE and IEAv), suggest that Coating and Surface Technology, along with Micro-Structural and Nano-Technology, show a significant increase in patenting activity, reflecting a growing interest in these areas. This indicates a focus on the research and development of new materials and technologies with advanced properties, potentially driven by demands for better performance and sustainability. Meanwhile, Semiconductors and Telecommunications maintain steady patenting activity, suggesting ongoing interest and investments in R&D&I in these critical areas for technological advancement and global connectivity.

Looking at Table 2 (ITA), we see that Instruments and Mechanical Engineering exhibit robust and consistent patenting activity, indicating sustained interest in these areas. This reflects the enduring importance of R&D&I in mechanics and precise instruments across various applications. The growing activity in Electrical Engineering is particularly notable in the later years of the table, signaling increasing interest in electrical and electronic technologies. This may be driven by trends such as vehicle electrification, renewable energy, and the need for more efficient power systems. Starting with "Strategic Areas for Investment," Table 1 (IAE and IEAv) specifically shows that in the area of Micro-Structural and Nano-Technology, consistent patenting activity indicates that this is a growing area of importance, with the potential to generate disruptive innovations in a wide range of applications, from advanced materials to electronics and medicine. Investing in research and development in this area could position an organization at the forefront of technology. Similarly, Semiconductors and Telecommunications continue to be crucial for technological advancement, driving innovations in communication, computing, and electronics; strategic investments in these sectors could boost the development of new technologies and products that meet the global demand for improved connectivity and performance.

Likewise, Table 2 (ITA) shows that Electrical Engineering has a growing patenting activity reflecting the importance of this area, particularly concerning sustainable technologies and energy efficiency. Investments here could pave the way for innovative developments in renewable energy, energy storage, and transportation electrification. Meanwhile, Instruments, with strong patenting activity, suggest that R&D&I in instrumentation is critical for advances in research and development across various fields; investing in precise and advanced measurement technologies could enhance innovation capabilities in sectors like manufacturing, life sciences, and environmental research.

Similarly, if we consider "Opportunities for Technology Transfer", Table 1 (IAE and IEAv) shows that the increase in patenting activity in Coating and Surface Technology suggests significant advances that could be applied in industries such as automotive, aerospace, and construction, offering opportunities for patent licensing or development partnerships. In the area of Optics, based on the observed patenting activity, there are opportunities to transfer optical technology solutions to sectors such as healthcare for medical equipment, or to communication and imaging systems, where improvements in these optical technologies could offer significant advantages.

On the other hand, Table 2 (ITA) shows strong consistency in Mechanical Engineering patenting activity, indicating that there are solid advances that could be applied in the industrial, automotive, and manufacturing sectors, suggesting opportunities for industrial partnerships or the commercialization of new innovations. Additionally, Chemistry, although showing less patenting activity, suggests that potential innovations in this area could impact sectors such as sustainable materials, biochemistry, and pharmaceuticals, which are currently in high demand globally.

Investing in technology transfer here could lead to innovative solutions that meet the emerging demand for greener products and production processes.

Conclusions

Based on the analyses presented above, it is clear that the patenting routine of the DCTA STIs over the past 19 years reveals a series of trends that should be observed and serve as a basis for strategic planning in the R&D sector, strategic innovation management, and the formulation of S&T&I policy for the STIs.

These analyses reveal the distinct dynamics of R&D and innovation, adapted to the trends and needs of their specific technological fields. IAE and IEAv stand out for their focus on specific technologies, such as advanced materials and communications, identifying areas with growth potential and research gaps that offer significant opportunities for innovation. In contrast, ITA demonstrates a consistent commitment to fundamental technological domains, evidencing a continuous interest in innovations in mechanical areas. These institutions recognize the importance of strategic areas for investment, especially in advanced technologies that are crucial to maintaining competitiveness and leading opportunities for innovation. The exploration of technology transfer opportunities, particularly in fields such as Coating, Surface Technology, Optics, Electrical Engineering, and Instruments, is highlighted as a means of expanding the impact of innovations across various sectors, promoting technological advancement and sustainable development.

This strategic approach not only underscores the complexity and multifaceted nature of the technological innovation process but also reinforces the need for S&T&I policies and innovation strategies that support research and development in these emerging and strategic areas. By identifying research gaps and focusing on areas of growing interest, institutions can direct efforts to maximize the impact of R&D&I, significantly contributing to technological progress and addressing global needs for sustainability and efficiency.

The evident diversity in patenting activities and areas of growing interest highlights the complexity of the innovation ecosystem in which these STIs operate (Aerospace and Defense), where opportunities and challenges coexist. This critical analysis focuses on the implications for research and development, as well as the impact on S&T&I policy and innovation strategy, derived from observations on periods of high patenting activity, innovation cycles, research gaps, and strategic areas for investment and technology transfer.

A proper identification of areas of intense patenting activity and growing interest provides a compass for directing research and development efforts. Strategic investments in domains such as Micro-Structural and Nano-Technology, Semiconductors, and Electrical Engineering are essential to maintaining technological leadership and responding to market demands. Simultaneously, identifying research gaps points to untapped potential in areas such as Engines, Pumps, and Chemistry, where renewed efforts could unlock disruptive innovations. Therefore, balancing the exploration of new territories and expanding known frontiers is crucial for a healthy and dynamic innovation ecosystem.

Regarding the impact of R&D&I policy and strategic innovation management, the former plays a vital role in shaping the environment for effective innovation. The conclusions drawn highlight the need for policies that foster research and development in areas identified as strategic, as well as facilitating technology transfer to maximize the social and economic impact of innovations. This includes investments in education and research infrastructure, tax incentives for R&D&I, and support for intellectual property. Additionally, an effective innovation strategy should include managerial mechanisms for the rapid adoption of emerging technologies in the public and private sectors, leveraging innovation to address global challenges such as sustainability, health, and security.

When examining the entire scope presented, the patenting activities of the DCTA STIs reveal a vibrant R&D&I landscape, with clear focus areas and potential for significant advancement. However, a successful strategy requires not only identifying these areas but also overcoming the inherent challenges in developing and implementing innovations. This includes addressing regulatory barriers, ensuring adequate funding, and promoting collaboration between industry, academia, and the government. Moreover, rapid technological evolution demands agility in R&D&I policies and innovation strategies, ensuring that they can adapt and respond to changes in the technological environment.

From a strategic innovation management perspective, the study highlights several key takeaways. Innovation is not a linear process; rather, it follows distinct cycles influenced by technological maturity, institutional priorities, and market demand. Recognizing these cycles enables better resource allocation, optimized technology transfer, and enhanced long-term research planning. Patent activity serves as both an outcome and a driver of innovation, shaping future research directions by signaling technological opportunities and guiding funding decisions. Institutions should leverage patent analytics not just for intellectual property protection but as a tool for strategic foresight and investment planning. Interdisciplinary and cross-sectoral innovation is critical for sustaining long-term competitiveness. The observed spillover effects between technological domains (e.g., materials science and optics, telecommunications and instrumentation) demonstrate the importance of collaborative research frameworks and open innovation models.

For policymakers and R&D&I leaders, these findings emphasize the need for flexible and adaptive innovation policies that:

- Encourage long-term research investment in foundational technologies while maintaining mechanisms to support high-impact, short-cycle innovation bursts.
- Strengthen industry-academia partnerships to maximize the economic and societal impact of innovation, ensuring that patenting efforts translate into technological applications.
- Leverage data-driven foresight mechanisms to anticipate technological shifts, aligning national and institutional research agendas with emerging global trends.

By integrating these strategic insights, organizations and policymakers can enhance their ability to anticipate, manage, and capitalize on the evolving R&D&I landscape, ensuring sustained technological progress and economic growth.

In conclusion, success in research and development, as well as in R&D&I policy and innovation strategy, depends on the ability to anticipate technological trends, strategically invest in promising areas, and facilitate the technology transfer process. A holistic and adaptive approach that considers both opportunities and challenges is essential to maximizing the impact of R&D&I and potential innovation, promoting sustainable development and technological progress.

The findings of this study reinforce the complexity and dynamic nature of the innovation ecosystem, where research, development, and patenting are interconnected through cyclical patterns of activity. The analysis of patenting trends within the three aeronautics institutes (IAE, IEAv, and ITA) provides critical insights into how technological priorities shift over time, how institutional research strategies evolve, and how external policy incentives shape innovation trajectories.

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