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Linkage Academia–Industry/Innovative High-Performance Systems: A Pathway to Strengthen Technological Capabilities for Innovation in Public Research Centers in Mexico

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Abstract: This study aims to create a reference framework to evaluate the technological capabilities (TCs) of public research centers in Mexico through their characterization, measurement, and statistical analysis for decision making on technological strengthening. Additionally, the study seeks to understand the context in which innovation and linkage activities occur within the research system and highlight the importance of integrating such studies into academic institutions. Using this generic framework, public research centers (PRCs), in addition to identifying weaknesses in the development of capabilities at the organizational level, could determine the level of development at which their TCs are located to address social demands and promote collaboration models between university and industry. To achieve this objective, 228 surveys were carried out per stage among researchers from the PRCs in Mexico. Each stage was composed of one questionnaire. Questionnaire 1 considered aspects of investment capabilities, assimilation, modification, support, and linkage. Questionnaire 2 was used to collect data on scientific productivity based on evaluation criteria established by the National Council of Humanities, Sciences and Technologies (CONAHCyT). The aspects covered included infrastructure, scientific publications, intellectual property, postgraduate programs, and collaborative projects. The results indicate that the majority of Mexican PRCs have developed basic and intermediate TCs, with 77% involved in applied research and technological development, but from the total research projects, only 8% present higher levels of technological maturity. The originality of the study lies in the quantitative measurement of TCs within the Mexican PRCs for the benefit of innovative and high-performance work systems, addressing a gap in the existing literature, and could be extrapolated to other universities of developing countries.

Keywords: technological capabilities; public research centers; scientific productivity; technological change; collaboration networks

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1. Introduction

The ability of organizations to take advantage of available knowledge and transform it into dynamic capabilities is crucial to respond competitively and innovatively to their specific conditions [1,2]. Dynamic capabilities promote in organizations the ability to change and reorganize their resources and environmental changes [3]. In this way, institutions or firms are interested in developing strategies that promote dynamic capabilities because they are a source of organizational results [4–6]. As part of the dynamic capabilities, technological capabilities (TCs) are critical to transforming technological knowledge into a competitive advantage and driving superior results compared to competitors [7–9]. TCs act as the foundation for developing new technological specializations, which are facilitated by skills, knowledge, experience, institutional structures, and networks [10–12]. These capabilities are cumulative and evolve over time, enabling organizations to create products and services that meet the demands of a dynamic economic environment, thus enhancing finance performance and maintaining competitiveness [13–15]. From a worldwide perspective, for new technological specializations to emerge, historical events also require the ability to develop new technological knowledge and innovative processes at a low cost. In this context, to guarantee an efficient relationship between TCs and innovative processes/products that impact as a driver of economic development, organizations must adapt to changing demands and obtain competitive advantages to succeed.

In developing countries, the intrinsic relationship between TCs and innovative products and services demands careful analysis within academic institutions, especially at the postgraduate level or within research centers. This analysis helps identify the types of TCs that can drive organizational development and differentiate them from other institutions. Therefore, research institutions are considered strategic assets as government instruments that link science and technology to societal advancement. They contribute to economic development by generating technological capabilities that foster innovation, strengthen academia–industry linkages, and drive sustainable growth. However, understanding the current state and potential of TCs within PRCs remains an underexplored area, and a structured framework for assessing these capabilities is essential. TCs are crucial for executing essential functions in PRCs and contributions to technological chance and economic growth. Most studies on the accumulation of TCs have focused on macro- and meso-level analyses, without an amination of individual skills, attitudes, and behaviors that contribute to organizational capabilities. This study addresses this gap by measuring and analyzing TCs in Mexican PRCs to diagnose their current state and identify their technological strengthening that helps to potentiate innovations in their institutions [16,17]. Like most institutions around the world, in Mexico, PRCs are responsible for generating and disseminating knowledge, transforming it into processes and products, and promoting innovation, hence significantly contributing to society and the national economy [18,19]. The assessment of the technological capabilities of PRCs can provide valuable insights into their role in driving technological change and supporting decision-making processes. Additionally, in recent years, PRCs have considered the development of sustainable projects as a transversal axis based on the international public policy agenda until 2030; which is particularly relevant in the planning and execution of innovation projects.

In this context, the study, by assessing technological capabilities in PRCs, provides a reference framework that is crucial to ensure that these capabilities contribute to sustainable development, specifically, in three aspects: (i) Sustainable innovation: The analysis of technological capabilities is essential to foster sustainable innovation. By assessing current levels of TCs in PRCs, the research facilitates a more efficient use of resources, helping to direct innovation efforts toward addressing societal challenges, including those related to sustainability. The findings, which reveal gaps in technological maturity, offer valuable

insights to strengthen the capacity of IPCs to drive responsible innovation that aligns with long-term environmental and societal goals. (ii) Socioeconomic impact: The collaboration between academia and industry is designed to promote the transfer of technological innovations that benefit both the economy and society. This directly supports the journal's goal of addressing socioeconomic challenges, as it fosters responsible economic growth while ensuring that technological advances are applied in ways that respect natural resource limits and contribute to social equity. The link between academia and industry drives the achievement of quality education, highlighting an important point such as research, which leads to the need for collaboration; this link facilitates and provides the exchange of knowledge and technology. Various studies have reported the numerous benefits achieved by carrying out research work between industry and academic institutions, such as the conversion of research-based technology to obtain new products and services [20]. In this context, the collaboration between academia and industry is promising; however, the main challenge they face in some cases is technology transfer; the difference in cultural norms and values between academic institutions and industry contributes to disagreements; for example, academic institutions prioritize the generation and dissemination of knowledge while industry wants to achieve knowledge application in diverse practical purposes [21]. These disagreements could be mitigated to strengthen sustainable education, in this sense, closing gaps by generating knowledge and skills to promote innovation and disseminating knowledge that promotes social and economic growth. (iii) Framework for sustainable growth: By establishing a structured method for assessing and improving IPCs, the study offers a tool for IPCs in which sustainable practices are embedded in their research and development processes. The framework ensures that IPCs can not only identify areas for improvement but also enhance their contributions to sustainable innovation, driving long-term technological and economic resilience in line with sustainability goals.

It is known that there is not enough knowledge about the aspects that influence the determination of the development of technological capabilities impact which are relevant to collaborative practices; therefore, the objective of this study is to establish a generic framework for assessing technological capabilities in PRCs. By identifying and evaluating these capabilities, the study will help to identify the decision-making process related to technological strengthening. Furthermore, the study seeks to understand the context in which innovation and linkage activities occur within the research system in Mexico, as an example of a developing country, and to highlight the importance of integrating such studies into academic institutions. This integration will promote the evolutionary processes of the adaptation and generation of knowledge, ultimately impacting the transfer of knowledge and the commercialization of technology within the framework of sustainable development. The structure of this research includes a state of the art on technological capabilities and their characteristics, an evaluation of the scientific production of PRCs, a detailed description of the methodology, an analysis and discussion of the results, and, finally, the conclusions. Surveys were carried out using two questionnaires (228 surveys for each stage) among researchers from the PRCs in Mexico. Questionnaire 1 considered aspects of investment capabilities, assimilation, modification, support, and linkage. Questionnaire 2 was used to collect data on scientific productivity based on evaluation criteria established by the National Council Of Humanities, Sciences And Technologies (CONAHCyT). The aspects covered included infrastructure, scientific publications, intellectual property, postgraduate programs, and collaborative projects.

2. Literature Review

2.1. Knowledge Management Evolution and Relationship with Innovation Process

The importance of knowledge management (KM) applied to different areas of knowledge has been noted for some time, leading to its classification as a structured discipline. KM classification can contribute to the process of capturing, storing, and sharing information and experience in organizations, helping technological evolution and academic research transformation. Initially, in the 1960s, the main concept that guided the evolution of KM was the classification of explicit and tacit knowledge. The first refers to knowledge documented in handbooks, research reports, sales scripts, and datasheets for categorization and sharing. The second concept of knowledge (tacit) includes the skills, abilities, ideas, and experiences of personnel within organizations [22]. This knowledge allows organizations to learn from experience through informal learning, which later evolved in the 1970s to provide knowledge processing within organizations (embedded knowledge). The establishment of the KM took place in the 1980s with the explanation of how tacit knowledge can be transformed into explicit knowledge and vice versa (socialization, externalization, combination, and internalization; SECI model) [23], additionally, the determination of intangible assets of an organization (human structural and relational capital; known as intellectual capital) [24], the advancement of technology (manual vs. automates process), and the creation of knowledge repositories (information systems) played a significant role [25]. Subsequently, the formalization of the KM was carried out (1990s) through the creation of knowledge-sharing systems and standards for codifying and storing knowledge (databases), but mainly with the development of software, theories, and concepts (knowledge cycle: creation, storage, sharing, and application) that allow KM to be recognized as a strategic function in organizations [26]. Important advances caused the institutionalization (2000s) of KM with the creation of specific organizations dedicated to KM, the recognition of these processes for strategic alignment, technological integration, and the formation of social networks for knowledge creation, etc. (relational knowledge) [27]. Between the 2010s and 2020s, the era of digitalization evolved the availability of information through big data analytics, cloud platforms, advanced collaborative tools, knowledge automation, the use of AI, and cognitive systems that enhance decision making and support knowledge workers [28]. Finally, the application of KM provided support for organizational and open innovation (the use of external knowledge to accelerate internal innovation, strategic knowledge) with a clear expansion beyond internal organizational knowledge [29]. Other types of innovations impacted by KM include immediate effects on organizational productivity, cost reduction, and new capabilities (technical innovation) as well as broader and longer term impacts, causing changes in the systems, policies, or market behavior (social innovations) [30]. In this context, the Organization for Economic Cooperation and Development (OECD) identifies actually two types of innovation: (a) product innovations and (b) business process innovations [31].

The integration of AI and machine learning has gained major relevance in a variety of areas, including the introduction of knowledge graphs. Post-COVID-19 knowledge management has been impacted by how the information can be shared between institutions, the tailoring of knowledge content (personalized knowledge), and a sustainable approach to all these items considering a global environment and social changes [32,33]. All these concepts can be used for a specific method or process, which is also known as procedural knowledge.

It is evident that the initial concepts in knowledge management were essential in the organizations to recognize and transition from informal procedures/practice to formalize technological methodologies, focusing on the role of human resources and digital tools. It is well recognized that explicit knowledge spreads across firms and countries due to

its codified nature, technological facilitation, transfer mechanism efficiency, and low cost. Similarly, tacit knowledge is essential to contribute to the development of technology and generate innovation in the organizations that can be transferred to other countries, but requires skills, experiences, knowledge, and insights that cannot easily be codified or written down. In this case, qualified employees are needed to improve the effectiveness [34].

From this information, it is clear that a relationship exists between the development of innovation and the transfer of technology with tacit knowledge, which can be strengthened through education in two ways: (a) Humans within the organization can be helped to acquire both explicit and tacit knowledge, laying the foundation for successful innovation and the eventual transfer of technology [35]. (b) Universities and research centers can develop strong relationships with firms/organizations that promote open innovation (solving complex problems) and at the same time improve their competitiveness.

2.2. Dynamic Capabilities as Tool for Evolution of Universities and PRCs in Mexico

On a global scale, it is widely recognized that universities and government research centers play a crucial role in the development of technological entrepreneurship and innovation, but at the same time, new learning technologies are required as a didactic response to the challenges that arose after COVID-19. Most academic institutions had to change their programs, educational approaches, or strategies to adapt to the external environment. In this context, the dynamic capabilities theory has been successfully applied to promote unique goals and strategies within a dynamic environment [36]. Previous authors confirm that changing the environmental dynamics in academic institutions helps to develop workforce skill sets and, consequently, the processes and practices that motivate the advancement of new knowledge and human capabilities which in turn support the achievement of internal goals [37]. The factors that have been identified in higher education that can be extended to other academic levels are the ability to sense the environment, organizational structure, adoption of information and communication technologies, organizational learning, human resource strategies, leadership, willingness to change, and collaboration with stakeholders [36,37]. Thus, the role of dynamic capabilities in universities contributes to reaching the third mission related to knowledge transfer and technology commercialization [37,38]. For example, countries such as the United States have proposed programs whose main goal is to promote scientific research and development through university–business collaboration [39]. The United Kingdom also has a strong university–business collaboration although their model is based on innovation programs (Innovate UK and Research England) with more active interaction of the government to promote public–private partnerships [40,41]. Another interesting model is in Germany where the university–firm relationship has a dual system of vocational education strengthening the industrial base through the Helmholtz association. The investigations have a high perspective of translating basic to applied projects, particularly with innovations in engineering, manufacturing, and high-tech industries. Germany's system is less oriented to entrepreneurship compared with the U.S. model [42,43]. It is evident that the creation of associations or governmental offices facilitates the industry–university collaboration; for example, in Japan, the New Energy and Industrial Technology Development Organization (NEDO) and a network of companies (Keiretsu) support these collaborations through funds with large corporations like Tokota, Hitachi, or Sony, promoting R&D projects or relevant projects with other countries [44]. The main interest in this case is fostering entrepreneurship through university spin-offs and technology transfer [45]. A growing development in innovation due to industry–academia collaborations can be observed in South Korea through the Korea Institute for Advancement of Technology (KIAT), where it is promoted that large conglomerates are closely linked to the universities, fostering technology transfer

startups [46,47]; whereas in China, academy–industry collaborations have changed rapidly, particularly in policies, with special emphasis on innovation oriented towards key areas such as artificial intelligence, robotics, biotechnology, and renewable energy [48]. For this reason, the research and innovation promoted by the academy–industry collaborations in China are directed by government offices, assuring a successful integration even with international partnerships [49].

Consequently, universities and research institutions are considered strategic assets, serving as key government instruments that connect science and technology with society [50]. In Mexico, the government institution in charge of coordinating and promoting international scientific and technological cooperation is the National Council of Humanities, Sciences and Technologies (CONAHCYT) [51]. Thus, CONAHCYT and its linkages with Mexican academic institutions (universities and public research centers, PRCs), as in many other countries, are an essential part of the economic development process due to technological advancement and innovation, i.e., the application of TCs to maximize the economic performance of society and catalyze skills in the academic institutions for the innovative process [52]. In the case of universities and PRCs, technological capabilities as part of dynamical capabilities are vital for the execution of essential technical functions, such as improvements in new technologies; development of new products, processes, and technological knowledge; human resources training; and economic growth [53]. Therefore, conducting an analysis to identify what type of TCs are available in each institution (universities or PRCs) that improve internal technological capabilities and benefit their organizational development will help to be a differentiator compared to others [8,54]. To our knowledge, most studies on the accumulation of technological capabilities have been applied in different firms to analyze the macro- and meso-levels, without an adequate analysis of the individual skills, attitudes, and behaviors that play into organizational capabilities [53]. Furthermore, these analyses have not been applied to educational organizations.

Previous research has reported some factors that limit knowledge development and research transfer in Mexico. The work reported by Nelly Medina et al. focused on research in biotechnology transfer of a leading research institute in Mexico, CINVESTAV. They agreed that, like other scientific institutions in Mexico, CINVESTAV has focused on basic research, without showing interest in long-term strategies to promote technological transfer. A striking fact reported by this work was that by carrying out collaborations between academia and industry, successful cases such as patent presentations with researchers from both organizations were obtained [55]. Another work that agrees with the benefits of the academia–industry linkage was reported by Paula et al. [56]; the purpose of this work was to contribute to the understanding of the effects generated by technology and knowledge transfer; specifically for research in the agri-food sector, it showed benefits such as new product creations, and improvement in the established processes and methodologies, and likewise, in the equipment development and prototypes or pilot plants, significantly favoring technological capabilities. Although there are several achievements in various research centers that carry out linkages with industries, in Mexico, the culture of linkage is still scarce due to the lack of exploitation, transfer and use, implementation, and transfer of knowledge to encourage the innovation creations; for this reason, tools are required that allow greater effectiveness in technological capabilities.

3. Background

3.1. Applications of Technological Capabilities for Education

Technological capabilities (TCs) are part of dynamic capabilities, which describe the skills, knowledge, technology, and learning experiences accumulated or developed by an organization, both internally and through external linkages with other organizations [57].

Although the dynamic capabilities introduced in 1997 by Teece et al. are generally applied to firms to identify competitive advantages as well as to analyze how competencies and resources can be developed [58,59], the evolution in the application of the dynamic capabilities has led to adjusting the fundamental level of organizational agility, linking it to cost-effectiveness strategies [60]. According to Bustinza et al. [53], technological capabilities demand the presence of not only organizational resources and knowledge, but also organizational mechanisms such as strategic management, innovation management, etc., which have organizational skills to integrate, build, and reconfigure competence in a changing competitive environment for innovative solutions.

The application of dynamic capabilities in academic institutions (higher education) was initially realized through a model as an analysis of strategic changes in universities [61], and it has been resumed to evaluate the relationship between the work environment and the evolution of the workforce skill set and the impact on the generation of new knowledge [37]. In this way, human capital and the work environment have been found to be the main factors in achieving organization goals and competitiveness, and through dynamic capabilities, they can promote the transformation of teaching strategies with a certain agility [36,62]. According to Marbello and co-authors; finances, resources, and values (internal capabilities) combined with the external capabilities (technological change, knowledge, and market opportunities) can also be joined to acquire sustainable performance and reach the expected global challenges of the academic institutions [63]. Then, the capability to integrate, build, and reconfigure internal and external competencies are necessary elements during the implementation strategy. For example, few studies correlate the independent and interactive effects of entrepreneurial behavior and competitive advantages with dynamic capabilities and university performance [64]. It is evident that an understanding of how universities or RCs diversify or specialize their knowledge exchange activities is still under study because it is multifactorial (internal and external environments) [4].

The development of TCs is a critical factor for organizational success, enabling institutions to design new processes, develop products, and enhance knowledge and skills within their unique environment [12,63]. Improving TCs requires understanding the technological and economic context relevant to the organization, continuously accumulating valuable knowledge, and effectively deploying technologies [65–67]. Additionally, developing TCs involves significant efforts and access to technology, accompanied by substantial investments for absorption, adaptation, and learning [14,68,69]. Organizations that efficiently develop TCs achieve long-term competitiveness [12,70,71]. Previous studies have revealed that scientific research is the main source by which academic institutes and industry acquire knowledge [72]. Therefore, as their innovation strategies are refined in TCs, the institutions and industry become more actively involved in knowledge generation and updating.

In this context, in developed countries, public policies supporting the generation and accumulation of TCs create favorable conditions for organizations to enhance innovation, competitiveness, and economic growth. These policies facilitate access to resources and foster collaboration, enabling academic institutions and industries to develop and apply new technologies more effectively. Conversely, in developing countries, the lack of R&D-focused policies often limits the ability of organizations to absorb and utilize knowledge, constraining their technological development even within universities and public/private research centers [73–75]. A recent study by Tello-Gamarra and Fitz-Oliviera determined a positive relationship between TCs and organizational performance in developing countries, highlighting that organizations that actively accumulate technological capabilities are better positioned for growth and development [15], whereas Alpkan and Gemici investigate the relationship between high-performance work systems and product innovation, determining that TCs play a mediating role between them [53]. These findings underscore the

importance of analyzing TCs in academic institutions from different perspectives and contexts, as tailored strategies are essential for overcoming external barriers and maximizing technological potential within organizations.

3.2. Development and Accumulation of Technological Capabilities

The positive effect of TCs on performance in developed and developing countries has been previously analyzed [76]. Some important aspects to highlight are that TCs are correlated by various sources of knowledge, external linkages, and innovation [77,78], although some dynamic capabilities are intangible, like new ideas, or embedded in equipment, infrastructure, and human skills (tacit knowledge as part of KM domain). To understand the role of TCs in developing countries, it is necessary to conceptualize and quantify them in companies or institutions [15,73,79]. TCs are classified by depth into basic, intermediate, and advanced levels and by categories such as investment, production, support, and linkage activities, which include technical functions such as decision making, project execution, production processes, product focus, internal and external linkages, and organizational structure [80,81]. The classification helps to analyze different aspects in organizations such as understanding and prioritizing specific needs of each level, investing in basic research for new knowledge, or adapting technologies for cutting-edge innovation. Additionally, it can help to promote the development of technologies from basic to advanced, and evaluate the competitive position, areas of improvement, and economic growth. Finally, their identification can promote in organizations internal or external collaboration to correct weak areas. It is important to highlight that these levels can evolve from one category to another over time. It has been identified that TCs can be accumulated in developing countries in two main ways: (i) importing technology and (ii) technological learning characterized by sharing, adapting, and developing knowledge [82]. Regardless of the classification, TC absorption involves different phases, each of which requires environmental understanding to cumulatively develop competencies; each stage complements and depends on each other [82–85], Table 1.

Table 1. Stage of technological capabilities.

Development Stage	Technological Capabilities
1. Identification of opportunities/problems 2. Exploration, study, and selection of technological solutions	Technological acquisition capabilities
3. Technological operation	Assimilation capabilities
4. Adaptation of technology to local conditions 5. Modification of technology in response to the environment	Modification capabilities (minor change)
6. Modification of processes or products (substantial change in the original technology) 7. Research and development	Innovation capabilities

For this reason, TCs in firms should be seen as a continuous process of knowledge accumulation, progressively addressing the needs identified through technological assimilation, which includes the integration of technological knowledge, experience in product development and marketing, trade secrets, patents, methods, procedures and equipment, and more [53,86]. The continuous development of TCs prevents stagnation, fostering progress from basic to advanced levels, with innovation as a key element. In industry, technical cooperation often begins with routine activities and evolves towards innovation capabilities, integrating R&D and the advanced design of new technologies/products [87].

Similarly, academic institutions with strong TCs can generate more educational and research value through alliances than those institutions with weak TCs. Therefore, TCs in academic organizations develop due to internal capabilities, technological changes, R&D, and collaborations with other universities, research institutes, and companies that require technological support and innovation. Theses interactions lead to technological strengthening, improving academic competitiveness in dynamic environments [88].

In particular, so that academic organizations (universities or PRCs) have an adequate proposal in research, development, technology, and innovation the detection, evolution, and accumulation of TCs is mandatory. In this way, a proper analysis of structures is required to identify opportunities, plan strategically, and manage technology effectively [89]. A general matrix based on Bell and Pavitt was proposed to identify the type of technological capabilities in academic institutions, as shown in Figure 1 [90]. It can be seen that academic institutions can categorize TCs into R&D, production, strategic planning, organizational relationships, organizational learning, resource management, and commercialization [91–94].

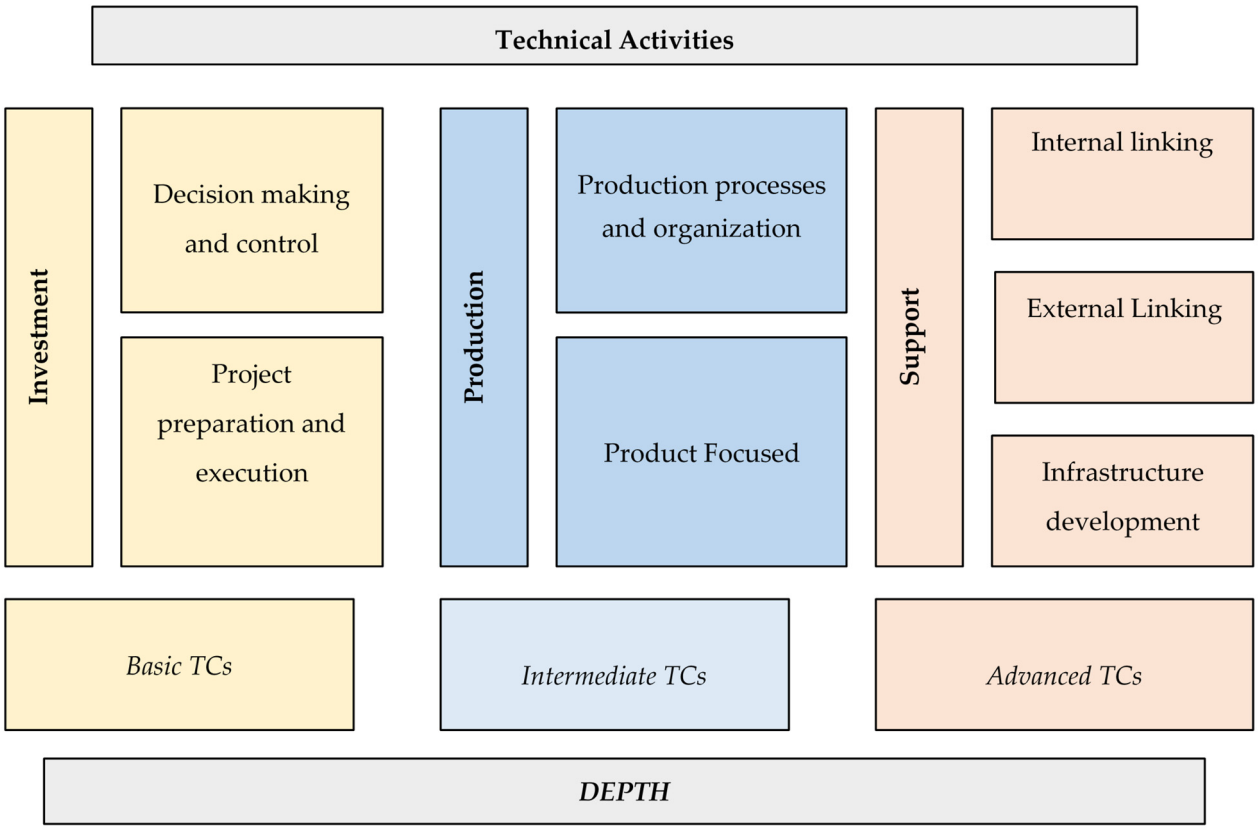

Figure 1. General matrix used to identify the type of technological capabilities [90].

The academic institute and industry collaboration significantly influence the core activities of teaching and research. Motivational drivers and prior collaborative experience play an important role in shaping TCs [95]. According to Montes et al. [96], promoting research activities in the industrial field can be carried out through innovation incentive programs; thus, they concluded that the best Mexican higher education institutions and research centers are key to establishing collaborations and, therefore, generating technological changes and knowledge generation.

As a final point of this section, in developing countries, essential TC activities identified within institutions can drive significant technological changes [87,97,98]. For example, Table 2 illustrates a matrix for TCs analysis of the energetic sector in Mexico based on profiles and the accumulation of the technological capabilities that have been observed

in Latin America [79,90,99]. It is clear from this table that as a deeper understanding of TCs is pursued, technological analysis activities become more complex, requiring greater absorption of tacit knowledge and development of skills. This trend is equally relevant to the academic sector. Progression through TCs levels requires the accumulation of tacit knowledge to support skills, decision making, and strategic planning [100]. Moreover, the development of the TCs process in academic institutions is neither linear nor uniform; it varies depending on each organization's needs and strengths. Nonetheless, the application of TCs is a critical requirement for enhancing technological development and innovation in developing countries.

Table 2. Matrix for TCs analysis of the industrial (energy) sector in Mexico [79,90,99].

	Primary Activities				**Support and Linkage Activities**	
	Investment		**Production**			
Level	Decision making and control	Project preparation and execution	Production processes and organization	Product focus	Linkage development	Team modification
Technological capabilities (to generate and manage technological change)						
Basic	-Active monitoring and control of: feasibility studies, selection of technologies, and programming of activities	-Feasibility studies -Obtaining standard equipment -Basic engineering assistants	-Start-up and operation -Optimization design and maintenance -Minor adjustments	-Repairs and technical adaptations to local physical conditions	-Research and absorption of information from suppliers, consumers, and institutions -Joint projects with other organizations. for training and education of human resources	-Easy adaptation of the existing designs and specifications
Intermediate	-Search, evaluation, and selection of technology -Negotiation with suppliers -Project management	-Detail engineering -Acquisition of equipment -Environmental valuation study -Project administration and monitoring -Training and recruitment (Trained manpower)	-Improvement of processes and products -New technology licenses -Introduction of organizational changes	-Licenses. New technologies and/or reverse engineering -Design of new components and equipment	-Technological link to increase efficiency, quality, and local supply -Maquila of equipment in national territory -Establishment of working groups between institutional partners	-Incremental innovation from reverse engineering and equipment design
Advanced	-Development of new products and components	-Basic design and R&D processes	-Process innovation and related R&D activities -Organizational innovation -Manpower formation	-Related R&D activities	-Collaboration in technological development -Process linking (university–company–government)	-R&D for designs of new products and components

3.3. Public Research Centers (PRCs) in Mexico

In public research centers, the identification and linking of technological capabilities with research activities is crucial to assess their level of development. This assessment allows us to understand how capabilities evolve in interaction with the environment and projects, and facilitates the classification of these capabilities into basic, intermediate, or advanced levels, which guides the prioritization of resources and technological development strategies [101,102].

Research shows that organizations that link their internal capabilities with strategic and scientifically relevant projects tend to achieve higher levels of development and impact [103–105].

The specific criteria that guide the classification, focused on the context of research centers, are as follows: (1) Technological independence, which refers to the research capacity to operate and solve technological problems without constantly depending on external knowledge. Thus, at the basic level, the research center depends significantly on external technologies; at the intermediate level, it can adapt and modify external technologies according to its needs, while at the advanced level, the center generates technologies autonomously and leads original developments. This demonstrates a high level of technological maturity that also contributes to the state of the art in its field [83,90]. (2) Degree of technical complexity, which refers to the specialization required to implement or develop technologies. At the basic level, the capabilities are limited or are of low complexity, such as the operation of standard technologies, while at the advanced level, the center develops cutting-edge technology using specialized tools and tacit knowledge to generate high-impact innovations [103]. (3) Capacity to innovate, which is the potential to generate innovative products, processes, or services. Again, at the basic level, innovation is limited to minor adaptations; at the intermediate level, incremental innovation is generated that optimizes technologies; and at the advanced level, solutions or products are created that transform the state of the art, which reflects a high degree of technological maturity [103,104]. (4) Sustainability of the technologies developed in environmental, economic, and social terms. The basic level is when the development of technologies does not always incorporate sustainability principles and dependence on limited resources is considered. At the intermediate level, the center optimizes resources and minimizes environmental impact. Finally, at the advanced level, the technologies are environmentally responsible, socially beneficial, economically viable, and comply with sustainability standards, that is, they reflect maturity in the integration of sustainability in technological development [104]. (5) Application or transferability, which refers to the capacity to apply technologies in the local context. At the basic level, the technologies are of limited application or depend on external adaptations. At the intermediate level, the center adapts and transfers technologies that generate practical benefits, whereas at the advanced level, the center demonstrates maturity in the generation of contextualized solutions and leads technology transfer processes [106,107]. Each of these criteria allows to define with greater precision the limits between basic, intermediate, and advanced capabilities. This helps the research centers to identify areas of improvement and to guide investments strategically. The classification of technological capabilities into specific levels allows them to assess the degree of maturity and the contribution of these capabilities to research [102,108].

The concept of technological maturity allows us to understand how technological capabilities are not limited to infrastructure or resources, but are also associated with the ability to integrate new knowledge (explicit), transfer technologies, carry out complex research activities, and innovate in an autonomous and scalable manner [109]. Therefore, a mature research center is capable of adopting and improving cutting-edge technologies in its research areas. With technological capabilities at an advanced level, it can anticipate

and adapt to technological changes, integrating new explicit knowledge autonomously and efficiently, generating innovations, and promoting self-sufficiency in research and development [83]. This classification allows research centers to evaluate and prioritize the development of their technological capabilities, guiding decision making regarding investment in infrastructure, personnel, and training, and directing their activities toward strengthening competitiveness and impact in their areas of specialty. Thus, the classification into basic, intermediate, and advanced levels not only facilitates the assessment of technological capabilities, but also justifies the allocation of resources in those strategic areas that contribute significantly to the scientific and technological development of the center. The assessment of technological capabilities is not a static process, but must be part of a strategy for continuous improvement. Centers must establish mechanisms to monitor and assess their capabilities on a regular basis, and adjust their strategies accordingly.

The development of technological capabilities in public research centers must be aligned with activities that address both the generation of new knowledge and its practical application. According to the organization for economic cooperation and development (OECD), these activities can be classified into (1) basic science (new scientific discoveries), (2) applied research (technological research), and (3) technological development (impact on social welfare through production, discoveries, and innovation), all of which contribute to economic and social progress through innovation and technology transfer. This framework allows capabilities to be direct towards high-impact strategic areas, promoting self-sufficiency and scientific competitiveness [110,111].

Evaluating and monitoring research requires consistent variables and indicators to describe the system's state and guide decisions [112]. Thus, public education (Universities or PRCs) in developing countries makes important efforts to generate valuable knowledge that is oriented towards the transfer of explicit knowledge or technologies to society and the market. The implementation of different strategies such as open innovation and the identification of dynamic capabilities can be a successful model to impulse a positive impact on society and the market in a specific area of interest [113].

In this context, Mexican PRCs have aimed to generate and share explicit knowledge, transform it into beneficial processes/products, and promote academia–public–private sector linkages since 1984 [114]; as many other developing countries, Mexico emphasizes improving the education system comprehensively and competitively [16], and then using TCs analysis as a key strategy to promote the technological process. Although some progress has been made in terms of scientific and technological capacity, there is no adequate monitoring or final implementation stage in the transfer of technology and innovation [115].

Despite their purpose, Mexican PRCs often function inadequately due to dependence on various actors and environmental influences; for example, reports of new explicit knowledge through research are common but do not guarantee that society will benefit from the products or services associated with them. Applications are rarely mentioned in the literature [116,117]; in fact, this problem can extend to other institutions in developing countries where reputation depends more on publications in high-impact scientific journals and higher income than on the transfer of explicit knowledge, technology, or innovation processes [113].

3.4. Evaluation of Scientific Productivity in PRCs

Scientific productivity is the research output produced by scientists, measured by different scientific indicators that determine policy, strategy, and operation decisions in PRCs [118,119]. It also reflects knowledge expression from scientific research, contributing to science development and economic growth [120–122].

Evaluating scientific productivity involves context-specific criteria, despite difficulties in quantifying research inputs and outputs [123]. This evaluation determines science growth and guides organizational systems by detailing work quality, resource allocation, and relationships between inputs and objectives [124]. An effective evaluation process includes the impact of research over time, addressing short- and long-term effects on social, economic, and scientific levels [112]. As expected, TCs identification helps PRCs improve or change scientists' publication patterns to improve product quality, create new processes, and generate knowledge. At the particular level of Mexico, the main public institutions with significant PRCs are the National Autonomous University of Mexico (UNAM), the National Council Of Humanities, Sciences And Technologies (CONAHCyT), and the National Polytechnic Institute (IPN) [125]. All Mexican PRCs establish research commitments based on their knowledge areas. CONAHCyT uses criteria from the Results-based Management Agreement (RMA) and the National Quality Postgraduate Program (NQPP) to measure scientific production. The RMA criteria include dissemination activities, postgraduate course quality, knowledge generation, human resources, economic sustainability, external projects, intellectual property, and knowledge transfer [126]. The NQPP criteria cover curriculum, student selection, academic trajectory, core faculty, knowledge generation, mobility, graduation rates, thesis quality, productivity, alumni networks, societal collaborations, evaluation compliance, and improvement plans [127]. Technology transfer in academic institutions depends on credible processes, administrative procedures, and management capabilities, supported by qualified human resources, infrastructure, funds, and motivation. Strategic TCs absorption or transfer aids Mexican PRCs in managing and creating technology for production processes.

Based on the above arguments and the fact that academic institutions with an innovative and entrepreneurial orientation are characterized by high-quality teaching outcomes and sustainable opportunities in the implementation of new teaching business models, the following hypotheses were proposed: Hypothesis 1: The TCs of the Mexican scientific–technological PRCs are positively correlated with their research activities, with PRCs using cutting-edge technologies to promote research production and impact. Hypothesis 2: Collaborations with national–international institutions, government funding, specialized infrastructure, innovation fostering, and researchers' skills at a PRC can positively influence the assimilation or development of TCs. Hypothesis 3: The development of advanced TCs at a PRC can significantly influence the advancement of new knowledge and accelerate the transition to applied solutions that improve their global competitiveness.

4. Materials and Methods

4.1. Research Questions and Taxonomies Used to Evaluate Dynamic Capabilities

This study analyzes the technological capabilities (TCs) of 48 public research centers (PRCs) in Mexico through a case study approach [128]. Case studies are ideal for answering "how" or "why" questions, particularly when examining current phenomena in a specific context without intervening in the subject matter. The research questions for this study based on the hypotheses H_1–H_3 are as follows:

(a) What technological capabilities are related to the research activities of Mexican scientific–technological PRCs?
(b) How are these TCs developed in PRCs?
(c) How do these TCs influence the development of science at PRCs?

This research follows a cross-sectional, quantitative design [129,130]. In the initial stage, the primary Mexican PRCs focused on scientific and technological research were identified using national science and technology databases and their official websites. Contact information for researchers, innovation and technology management personnel,

and managers at these PRCs was collected. Considering the importance of characterizing, understanding, and improving TCs—from utilizing the existing resources to fostering innovation [87]—the TCs related to research activities were identified. This identification was based on taxonomies developed by Bell and Pavitt [90] and Ortega-Rangel [84]. These taxonomies were used to evaluate technological activities that build TCs and drive specialized changes in organizational processes, Table 3. The methodology of analysis was divided into two steps: in the first, a Likert scale questionnaire was created to determine and evaluate the TCs linked to the research activities of Mexican PRCs through 228 surveys of 48 PRCs (see Supplementary Material). This questionnaire, labeled as 1, included aspects such as investment capabilities, assimilation, modification, support, and linkage. It was validated through expert judgment and its reliability was assessed using Cronbach's alpha index with a minimum acceptable reliability coefficient of 0.7 [131]; see Supplementary Material. It is important to mention that Cronbach's alpha allows us to assess whether the items or questions are measuring the same construct or latent variable, which is essential to ensure the validity of the results. To determine the relationship between different TCs, the Pearson correlation coefficient was used, addressing the first two research questions of the survey 1. This statistical analysis measures the linear relationship between two variables, which is key to understanding the links between TCs and research activities. Pearson not only identifies the existence of a link, but also whether it is positive or negative, and its degree of intensity, providing a more detailed understanding of the interactions between variables.

Table 3. Technological capability frameworks created by different authors and used to evaluate technological capabilities in PRCs.

References	**Variables**				
[132]		Investment	Production		Support activities and Linkage
[133]		Decision making	Production process		
[84]	Technological capabilities	Technological acquisition	Assimilation	Modification	Innovation
[79,90]	Basic Intermediate Advanced	-Project management -Technology used -Research staff	-Use of knowledge -Research activities -Technological validation	-Technological development -Product development	-Technological Services -Intellectual property -Scientific–technological collaboration

4.2. Scientific Productivity Evaluation

Since scientific productivity results from research activities and given the importance of evaluating the relationship between research efforts and outcomes, a second questionnaire was developed (step 2, see Supplementary Material) [134,135]. This questionnaire 2 did not have the same structured as questionnaire 1, but instead aimed to collect data on scientific productivity based on evaluation criteria established by CONAHCyT (RMA and NQPP). This questionnaire was sent through the platform of the National Institute Of Transparency And Access To Public Information to the PRCs. It was later responded to by the liaison coordination and technical management. A total of 48 questionnaires were answered, one for each PRC. The aspects covered included infrastructure, scientific publications, intellectual property, postgraduate programs, and collaborative projects. The content was validated through expert judgment.

The relationship between the TCs of the PRCs and the results of their scientific productivity was analyzed using the Pearson correlation coefficient. This analysis aimed to determine and understand the impact of TCs on scientific production, thereby answering the third research question. It is important to mention that an important limitation of this work is that Pearson correlation is commonly used to evaluate relationships between variables, but it is limited to bivariate relationships and can change when control variables are introduced.

5. Results

5.1. Data Collected

The research employed a methodological tool developed from previous studies aimed at identifying the technological activities that underpin the technological capabilities (TCs) capable of generating technological change. Table 4 outlines the three levels of evolution of TCs within the PRCs, increasing in complexity and depth of knowledge as they advance. The key TCs examined include 1. project management, 2. technology used for research, 3. research personnel, 4. the use of scientific–technological knowledge, 5. research activities, 6. validation of technology, 7. development of technology, 8. development of products, 9. technological services, 10. intellectual/industrial protection, 11. scientific–technological linkages.

Table 4. Matrix prepared for the identification of technological capabilities based on different authors [84,90].

CT	**Investment**		**Production**			**Support and Linkage/Innovation**
			Assimilation Modification/Innovation			
Technical Function	Decision making and control	Project preparation and implementation	Production processes and organization	Technological development	Production focused on product	Linkage development
Technological capabilities (to generate and manage technological change)						
Basic (B)	B.1 Technological research projects commissioned by a higher authority body	B.2 Acquisition of standard technology B.3 Technicians for basic engineering	B.4 Application of prior knowledge B.5 Basic science research B.6 Technological validation in the laboratory	B.7 Simple adaptation of the existing designs and specifications	B.8 Incremental improvement of product quality (process to make a minor upgrade to an existing product in the market)	B.9 Technological services without certification B.10 Acquisition of technology licenses B.11 Research groups within the PRCs
Intermediate (I)	I.1 Management of own technological research projects authorized by higher authorities	I.2 Acquisition of specialized technology I.3 Technicians for detailed engineering (training or recruitment of trained personnel)	I.4 Generation of new knowledge I.5 Applied research/technological development I.6 Technological validation in an environment similar to the real	I.7 Technological development/minor adaptations	I.8 Incremental design of new products (a model to realize small improvements until the product is complete)	I.9 Technology services with national certification I.10 Generation of intellectual property I.11 Research collaborative groups between national partners
Advanced (Z)	Z.1 Generation and management of own research projects	Z.2 Development of own technology Z.3 Researchers (specialization or recruitment)	Z.4 Dissemination abroad of new knowledge Z.5 Technology demonstration/complete prototypes Z.6 Technological validation in real environment	Z.7 Technological development/R&D for new product and equipment designs—Innovation incremental	Z.8 New product development—Radical innovation by related R&D (technology breakthrough creating a new market opportunity and a long-term economic impact)	Z.9 Technology services with international certification Z.10 Technology transfer/commercialization of intellectual property abroad Z.11 International collaboration networks in technological development

The characterization of technological capabilities (TCs) varies depending on the type of organization developing them and the sector to which it belongs. For instance, a study on the evolution of TCs in the Indian automotive industry and the necessary public policies for updating these capabilities categorized TCs into three levels: basic (operational capabilities), intermediate (reproduction and adaptation capabilities), and advanced (innovation

capabilities). The findings were pivotal in formulating public policies to enhance these capabilities in India's automotive sector [87]. Similarly, research by Roshartini et al. on TCs measurement in technology transfer projects evaluated and compared these capabilities in six different construction sector companies [136]. For example, the evaluation of the technology usage capability revealed different development levels: use of incorporated technology (basic level), use of new imported equipment (intermediate level), and technology obtained through the company's R&D (advanced level). The results facilitated the creation of a framework for assessing TCs in technology transfer projects within the Malaysian construction sector.

On the other hand, TCs have an important relation with institutions' academic collaborations; in México, the research and knowledge are acquired mainly in local collaboration, and international collaboration still has little influence; however, this fact is not shared by other areas of knowledge in Mexico [137]; the identification of the TCs of Mexican PRCs reflect the impact that this research has on technological development. In this sense, the need to promote technology transfer between academia and industries acquires great relevance. This is a process in which technological capabilities have a great role, mainly its potential practical engineering applications as science and technology generation; a part of technological development and innovation is the result of the knowledge academic institutions generate by existing in a variety of mechanisms to achieve it. Overall, the proposed method shows the benefit of enhancing technological capabilities in which research centers can maximize the benefits of technological transfer. In addition, a part of academic and industry productivity can be patents, pilot plants, methodology implementations, scientific publications, etc. [56].

As for research and development (R&D) organizations, they aim to develop solutions that translate scientific research into advanced products and services. Since advanced technological capabilities are an essential requirement for their competitiveness, these organizations must be able to analyze and evaluate them in a practical and objective manner. This enables a comprehensive understanding of their research competencies, the technologies they use and develop, and their scientific and technological links [138]. In the context of technological audits, three key dimensions for evaluating the technological maturity of R&D organizations are identified [139]. These include the technological base as the input dimension, the development of products and services as the output dimension, and technological cooperation and synergies as the third dimension. Based on the aforementioned matrix, a questionnaire was designed as a methodological tool, including a taxonomic separation of TCs levels applicable to public research centers (PRCs). This instrument was validated by eight experts (PRC scientists, technological staff, and university academics), incorporating their suggestions into the final version. The questionnaire consisted of 33 questions to identify the TCs of Mexican PRCs. Responses were collected using a Likert scale with a five-point frequency scale: 1 = never, 2 = rarely, 3 = occasionally, 4 = frequently, 5 = very frequently. Table 5 shows, as an example, the determination of the level of development of each TC from the PRCs considering the previous criteria. It is important to note that to maintain the confidentiality of each research center, they were labeled from 1 to 48, so this table shows the analysis of six PRCs that were randomly selected at each level of development.

Initially, the questionnaire was administered to 25 researchers from different PRCs, achieving a reliability index of 0.852 for Cronbach's alpha coefficient. Subsequently, the survey was expanded to include members of research groups from the three main public research institutions in Mexico where most scientific productivity resides: the National Council of Science and Technology (CONAHCyT), the National Polytechnic Institute (IPN), and the National Autonomous University of Mexico (UNAM). The survey was distributed

through the Survio® platform, and the data were analyzed using the constant comparative method. The response rates were 70% from CONAHCyT, 60% from IPN, and 60% from UNAM, totaling 48 PRCs (228 surveys).

Table 5. Level of development of each TCs in the evaluated PRC considering the above criteria.

Identification of PRCs	Frequency of TCs by Level of Development			Criterion	TCs Level by PRCs
	B.1	I.1	Z.1		
17	2	3	5	1	Advanced
18	4	5	4	2	Intermediate
19	2	4	3	3	Intermediate
20	3	4	4	3	Intermediate
13	4	2	1	4	Basic
32	3	3	3	5	Basic

5.2. Determination of TCs on PRCs

The collected data were analyzed to determine the development level of each TC within the PRCs using the following criteria based on the frequency scale:

Advanced level, when Criterion 1: The PRC very frequently develops TCs at this level. Intermediate level, when Criterion 2: TC develops very frequently at this level, while at the advanced level, it has a lower frequency. Criterion 3: TC develops frequently at this level, and at the advanced level, it has the same or lower frequency. Basic level, when Criterion 4: The frequency of TC at this level is the highest. Criterion 5: TC is performed occasionally or at lower frequencies across all three levels.

Figure 2 shows the level of investment capabilities in the PRC, indicating that 66.67% develop the intermediate level of project management (I.1). This means they manage their own technological research projects, which are pre-approved by their higher institutions, adhering to institutional resource management protocols. The literature suggests that research centers, especially in developing countries, operate under institutional oversight protocols that limit resource management [79,140].

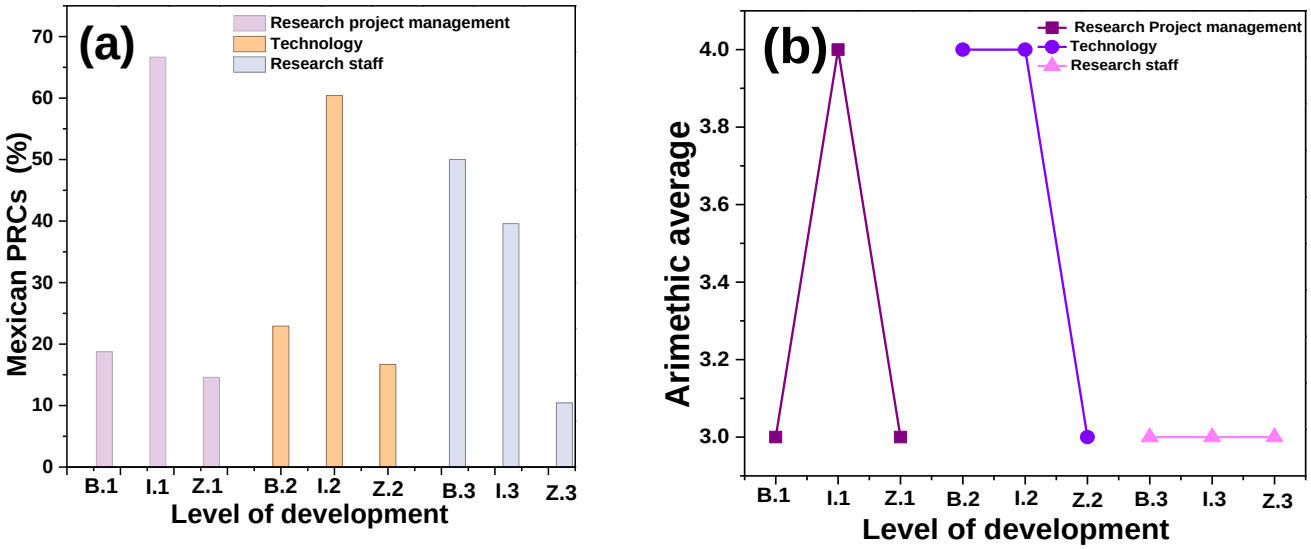

Figure 2. Evaluation of investment capabilities identified in the PRCs: (**a**) percentage for each item and (**b**) arithmetic average.

This coincides with the aforementioned data, in which only 14.58% handle and administer their projects independently and autonomously (Z.1). Similarly, in technology usage, 60% of the PRCs are at the intermediate level (I.2), while just over 15% develop

their own technology for research activities (Z.2). The data also reveal that 77% of PRCs conduct applied research, whereas only 8% operate at an advanced level (Figure 3). These findings confirm that the research context significantly impacts TCs development, responding to internal stimuli, such as the availability of resources, and external ones, such as environmental demands [79,132].

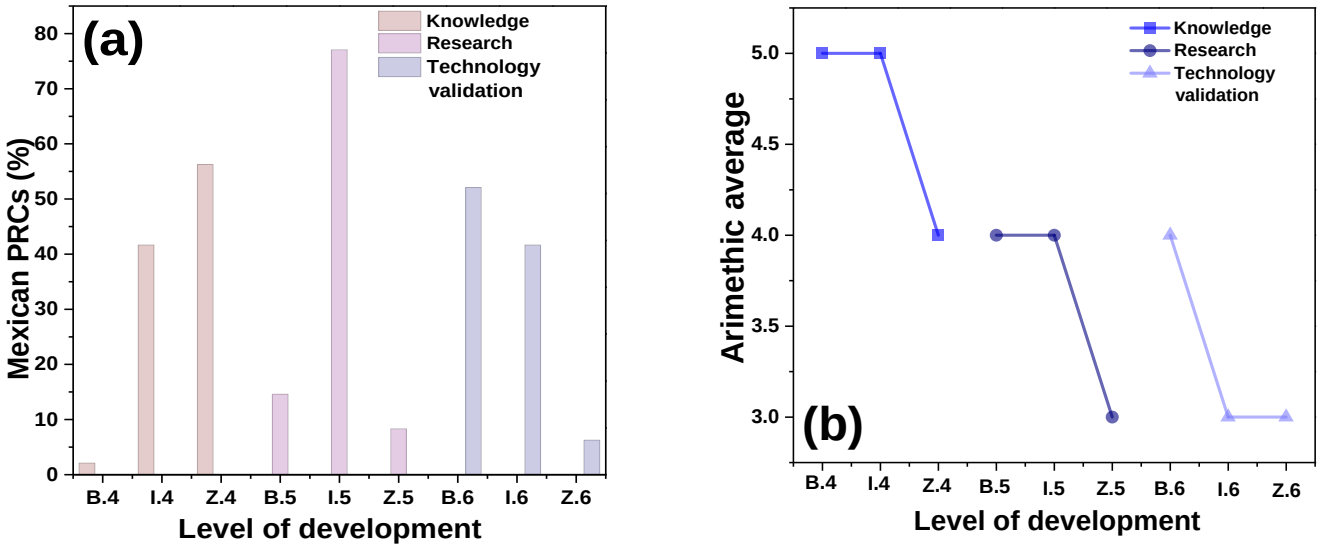

Figure 3. Evaluation of assimilation capabilities identified in the Mexican PRCs: (**a**) percentage for each item and (**b**) arithmetic average.

Some studies suggest that in organizations with greater autonomy in resource management, research staff tend to use advanced technologies, adapt quickly to new tools, and show more receptiveness to innovation, thereby enhancing the effectiveness of their research activities [15,140].

For the studied PRCs, innovation capabilities are primarily at a basic level, likely due to the challenges public centers face in managing resources autonomously. This limitation impacts their R&D capabilities (Figure 4), often constrained by budget and resource limitations, unless supplemented by external industry collaborations.

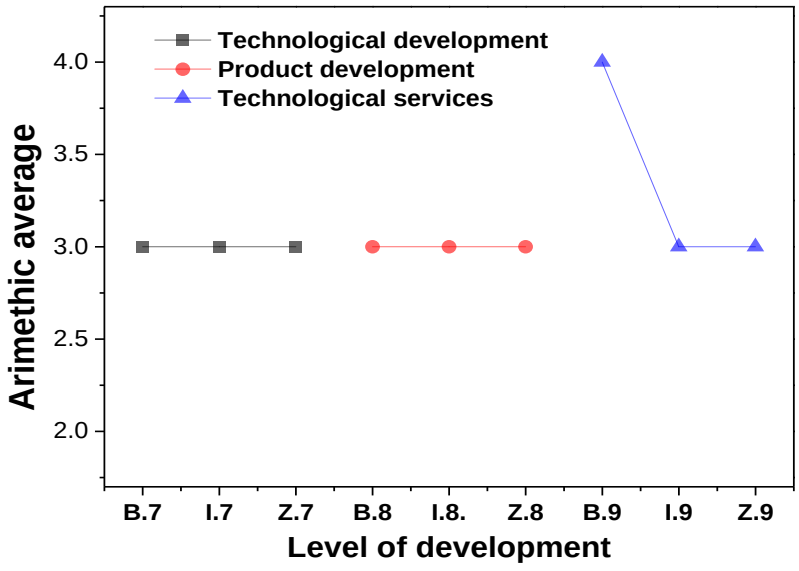

Figure 4. Evaluation of R&D capabilities identified in the PRCs showing the arithmetic average.

Collaboration through research groups and networks has been identified as a crucial factor for the development of TCs [138,141], particularly in environments with limited funding and resources, as is the case in some developing countries [15,142]. Moreover, recent studies indicate that collaboration allows the exchange of knowledge and technology, which is essential for institutions to access advanced knowledge, infrastructure, and capabilities they might otherwise lack [141]. These TCs are essential for establishing collaborative links with both national and international research groups, enhancing technological, innovative, and competitive performance [99]. Collaborative networks strengthen learning and innovation, improving problem-solving abilities and competitive advantage within the context of national innovation systems [143]. However, limited or absent collaborations hinder technological innovation [59,144,145]. In a dynamic and competitive socioeconomic environment, the ability to innovate is vital for survival and success [146]. Therefore, according to the results, it is critical for 27% of the Mexican PRCs at the basic level of collaboration TCs (B.11) (Figure 5) to pool efforts and funds into investment and assimilation TCs. Currently, 58% and 37% of the PRCs are at the basic and intermediate levels of these capabilities, respectively. So, access to international or interinstitutional knowledge is fundamental for the creation of local TCs, especially in emerging economies [79,142,143].

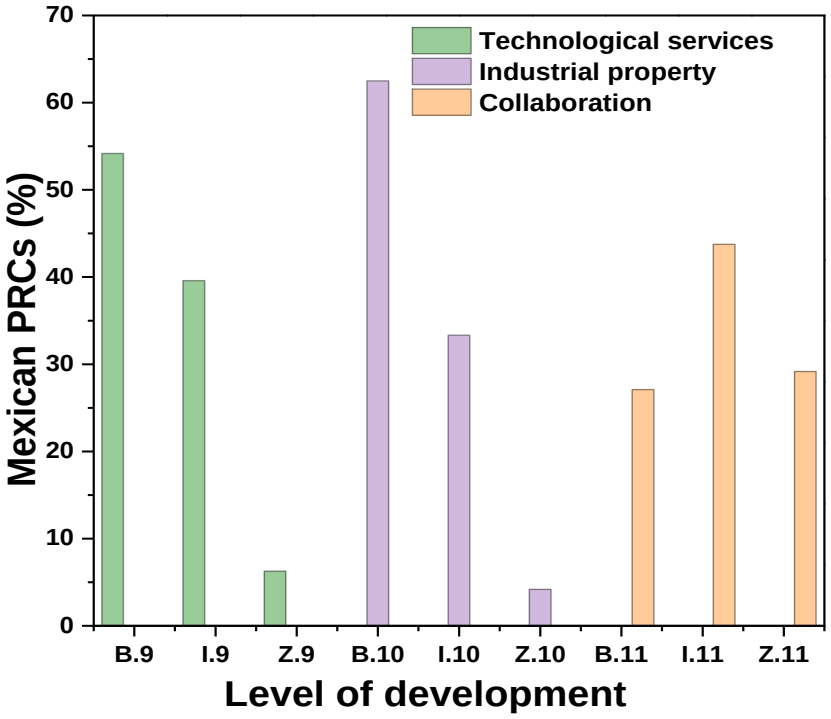

Figure 5. Evaluation of support and linking capabilities identified in the PRCs showing the percentage of each item.

In Mexico, as in other Latin American countries, this cooperation is not only key to technological development, but also to improving competitiveness in strategic sectors [15,79]. However, because a large portion of the Mexican PRCs is at the basic or intermediate levels of collaborative capabilities, their potential to contribute significantly to the country's economic and technological development is limited.

On the other hand, intellectual/industrial property capabilities and their commercialization are essential for public research centers to generate income that can finance future research [147]. Some studies indicate that research institutions in developing countries often face difficulties in advancing these capabilities due to several factors: a lack of experience in commercialization, weak legal and regulatory frameworks, and limited interaction

with industry [141]. Figure 5 shows that only 4% of the PRCs have developed intellectual/industrial property capability at an advanced level, reflecting a structural limitation that is also observed in other countries in the region [148], while 33% are at an intermediate level. This suggests that most PRCs do not commercialize the intellectual/industrial property they generate, even though a third practices intellectual protection. This problem of intellectual property highlights the need for policies that encourage the commercialization and transfer of technology, such as alliances with private companies or the establishment of specialized technology transfer offices [85,149]. These limitations affect their ability to generate resources that could fund future research. The results also underscore the importance of collaboration and its impact on the development of innovation capabilities, noting that 29% of the PRCs that develop collaboration capabilities at an advanced level engage in technological innovation. The literature warns that these processes require a considerable support infrastructure and a culture of innovation that is still in the process of development in public research centers in developing countries [148,150].

5.3. Statistical Analysis

To measure the relationship between variables, a statistical analysis was conducted using the Pearson correlation coefficient (r), with a sample size of 48 (N) and a significance level of $p = 0.05$, utilizing IBM SPSS (Statistical Package for the Social Sciences) version 21. The data were analyzed to compare and determine the existence of a statistical relationship between the TCs of innovation and the support and linkage TCs of the PRCs. The correlation strength is interpreted as follows: a strong correlation exists when $1 > r \geq 0.50$ and $p \leq 0.05$, a moderate correlation when $0.50 > r \geq 0.30$ and $p \leq 0.05$, a weak correlation when $0.30 > r \geq 0.10$ and $p > 0.05$, and null when $0.10 > r \geq 0.00$. Table 6 displays the Pearson correlation indexes between scientific–technological linkage capabilities at intermediate and advanced levels (I.11 and Z.11) with technological activities related to innovation at the intermediate and advanced levels, such as technological development (I.7 and Z.7) and product development (I.8 and Z.8), as well as the advanced level of intellectual/industrial property (Z.10).

Table 6. Pearson correlation to assess the collaboration capabilities of PRCs.

		I.11	**Z.11**	**I.7**	**I.8**	**I.10**	**Z.7**	**Z.8**	**Z.10**
I.11	Pearson Correlation	1	0.362 **	0.510 **	0.580 **	0.286 *	0.355 **	0.336 **	0.392 **
	Significance		0.006	0.000	0.000	0.024	0.007	0.010	0.003
Z.11	Pearson Correlation	0.362 **	1	0.391 **	0.281 *	0.222	0.263 *	0.484 **	0.792 **
	Significance	0.006		0.003	0.027	0.065	0.035	0.000	0.000
1.7	Pearson Correlation	0.510 **	0.391 **	1	0.306 *	0.369 **	0.532 **	0.538 **	0.281 *
	Significance	0.000	0.003		0.017	0.005	0.000	0.000	0.026
I.8	Pearson Correlation	0.580 **	0.281 *	0.306 *	1	−0.086	−0.081	0.162	0.435 **
	Significance	0.000	0.027	0.017		0.280	0.293	0.135	0.001
I.10	Pearson Correlation	0.286 *	0.222	0.369 **	−0.086	1	0.563 **	0.457 **	0.170
	Significance	0.024	0.065	0.005	0.280		0.000	0.001	0.125
Z.7	Pearson Correlation	0.355 **	0.263 *	0.532 **	−0.081	0.563 **	1	0.722 **	0.132
	Significance	0.007	0.035	0.000	0.293	0.000		0.000	0.186

Table 6. *Cont.*

		I.11	Z.11	I.7	I.8	I.10	Z.7	Z.8	Z.10
Z.8	Pearson Correlation	0.336 **	0.484 **	0.538 **	0.162	0.457 **	0.722 **	1	0.191
	Significance	0.010	0.000	0.000	0.135	0.001	0.000		0.097
Z.10	Pearson Correlation	0.392 **	0.792 **	0.281 *	0.435 **	0.170	0.132	0.191	1
	Significance	0.003	0.000	0.026	0.001	0.125	0.186	0.097	

* the correlation is significant at the 0.05 level (unilateral); ** the correlation is significant at the 0.01 level (unilateral). These interactions were highlighted with the background color.

The correlation between national collaboration groups (I.11) and technological developments with minor adaptations (I.7) (r = 0.510, p = 0.000) and the incremental product design (I.8) (r = 0.580, p = 0.000) aligns with literature, which often highlights that domestic collaboration fosters learning and incremental innovation [94,151]. The observed moderate positive correlation between the advanced level of these capabilities, the technological developments of R&D for the design of new equipment and/or products with incremental innovation (Z.7) (r = 0.355, p = 0.007), and the development of new radical innovation products (Z.8) (r = 0.336, p = 0.01) aligns with the notion that radical innovation typically requires diverse inputs and innovative resources that are more accessible in international collaborations. While national collaboration may contribute to advanced technological developments, it often lacks the diversity and resource availability of international networks, which are more conducive to radical innovation [152].

Additionally, technology transfer (advanced level of intellectual/industrial property capability, Z.10) is positively and moderately correlated with collaboration in national research groups (r = 0.392, p = 0.003), which is consistent with the literature on intellectual property flows in innovation ecosystems, suggesting that national collaborations often support the refinement and application of intellectual property in environments where proximity facilitates control and communication [153].

Regarding the advanced level of scientific–technological linkage capability, which involves international network collaboration (Z.11), the results show a high positive correlation with the transfer and/or commercialization of intellectual/industrial property (Z.10) (r = 0.792, p = 0.000) and with the development of new radical innovation products (Z.8) (r = 0.484, p = 0.000). These correlations are consistent with studies indicating that international collaborations are key to accessing diverse resources that support high-level innovation and advanced technological knowledge, aligned with the open innovation model, highlighting the importance of fostering transformative innovation, especially when research centers aim to achieve commercial intellectual property success.

There is a moderate correlation between technological developments and minor adaptations (I.7). As mentioned above, the percentage of PRCs that generate and/or commercialize intellectual property is low. However, these results reflect the effect of their efforts in technological development, product development, and collaborations, as these have evolved to intermediate and advanced levels. Therefore, it was considered important to determine the relationship between technological and product development capabilities with the use and management of intellectual/industrial property. To this end, a statistical analysis was conducted using the Pearson correlation coefficient between technological development capabilities (I.7 and Z.7) and product development (I.8 and Z.8) with intellectual/industrial property capabilities (I.10 and Z.10).

Table 7 shows the correlations between intellectual property and innovation capabilities. The technological development of R&D for the design of new equipment and/or products with incremental innovation (Z.7) and the development of new radical innova-

tion products (Z.8) have a high positive correlation (r = 0.563, p = 0.000) and a moderate correlation (r = 0.457, p = 0.001), respectively, with the generation of intellectual property (I.10). This capability is also moderately correlated with technological developments with minor adaptations (I.7) (r = 0.369, p = 0.005). Similarly, the incremental design of new products (intermediate level of product development, I.8) has a moderate positive correlation with technology transfer (advanced level of intellectual property, Z.10) (r = 0.435, p = 0.001). These results support the idea that even incremental innovation processes benefit from intellectual property, though the impact may be less pronounced than in radical innovations [149].

Table 7. Pearson correlations between intellectual property and innovation capabilities of the PRCs.

		I.10	Z.10	I.7	I.8	Z.7	Z.8
I.10	Pearson Correlation	1	0.170	0.369 **	−0.86	0.563 **	0.457 **
	Significance		0.125	0.005	0.280	0.000	0.001
Z.10	Pearson Correlation	0.170	1	0.281 *	0.435 **	0.132	0.191
	Significance	0.125		0.026	0.001	0.186	0.097
1.7	Pearson Correlation	0.369 **	0.281 *	1	0.306 *	0.532 **	0.538 **
	Significance	0.005	0.026		0.017	0.000	0.000
I.8	Pearson Correlation	−0.86	0.435 **	0.306 *	1	−0.081	0.162
	Significance	0.280	0.001	0.017		0.293	0.135
Z.7	Pearson Correlation	0.563 **	0.132	0.532 **	−0.081	1	0.722 **
	Significance	0.000	0.186	0.000	0.293		0.000
Z.8	Pearson Correlation	0.457 **	0.191	0.538 **	0.162	0.722 **	1
	Significance	0.001	0.097	0.000	0.135	0.000	

* the correlation is significant at the 0.05 level (unilateral). ** the correlation is significant at the 0.01 level (unilateral). These interactions were highlighted with the background color.

These results indicate that although the innovation capabilities within the PRCs are developed, they need to be driven towards the highest levels of development to fulfill their intended purposes [18]. As these capabilities advance, intellectual property capabilities must also evolve. PRCs must be technologically capable of offering superior technology compared to what is available in the commercial market. Intellectual property, as a success factor for projects, supports the credibility of research-focused organizations and contributes to the successful commercialization of technology [154]. This is confirmed in the PRCs studied, where, despite only 4% being at the advanced level of intellectual property capability, 31% practice it frequently.

5.4. Framework Construction

From the questionnaire 1 responses and statistical analysis, the technological capabilities (TCs) of the PRCs related to technological change were identified, leading to the construction of the framework shown in Table 8.

Table 8. Framework of technological capabilities of Mexican PRCs.

Categories	Investment	Assimilation	Innovation	Support and Linking
TCs for technological change	Project Management	Use of scientific knowledge	Technological development	Technological Services
	Technology usage	Research activities	Product Development	Intellectual property usage
	Research staff	Technological validation		Scientific–technological collaboration

The primary contribution of this proposed framework is the adaptation of TCs to the context of scientific–technological-based PRCs. It integrates concepts related to the levels of various project management processes, the use of scientific–technological knowledge, research staff, technological and product development, technological validation, types of technological services, the use of intellectual/industrial property, and scientific–technological collaboration. In the final stage of the research, it was necessary to determine the statistical relationship between the technological capabilities of the PRCs and the results of their scientific production. For this purpose, a second questionnaire was constructed to collect data for the period from 2014 to 2019. This questionnaire was based on the criteria established by CONAHCyT to evaluate the PRCs through the Resource Management Agreement (RMA) and the National Quality Postgraduate Program (NQPP) (Table 9). The instrument was also distributed through the Survio® platform with a response rate of 70% from CONAHCyT, 60% from IPN, and 60% from UNAM, totaling 48 PRCs.

Table 9. Categories and evaluation criteria for PRCs scientific production based on RMA criteria (CONAHCyT, 2015) [126] and NQPP (CONAHCyT, 2019) [127].

Category	Criteria
Available base	Staff dedicated to research (total number of researchers and total number of research technicians) Total lines of research Infrastructure (total number of laboratories)
Scientific–academic productivity	Scientific and academic publications carried out by research staff (total research articles in journals with impact factor, total book chapters, and total books published) Graduate programs with the NQPP-CONAHCyT distinction (total programs and total graduates)
Transfer of knowledge	Intellectual/industrial property (total patents applications, total patents granted, total utility models applications, total utility models granted, and total trademarks) Scientific–technological collaborations (total of national research groups, total of international research groups, total of national thematic networks, and total of international thematic networks) Linking projects (total projects with industry, total projects with public services, and total projects by government calls)

The instrument was validated by seven experts, who are researchers assigned to different research centers and national academic institutions. The information was requested from the previously studied public research centers (PRCs) through the platform of the National Institute of Transparency and Access to Information (INAI). The statistical analysis was carried out using Pearson's correlation to compare and determine the existence of a statistical relationship between the technological capabilities (TCs) of the studied PRCs and their scientific production achieved during the period 2014–2019, Table 10.

The results show that regarding investment capabilities, TC 1 (project management) only maintains a weak positive correlation with the utility models granted (r = 0.289, p = 0.047). TC 2 (technology usage) is not directly related to the results of scientific production, whereas TC 3 (research staff) has a moderate positive correlation with the total number of completed technology transfers (r = 0.306, p = 0.035). Coombs and Bierly argue that the speed to innovate is linked to the speed at which organizations use new technologies [155]. However, these results demonstrate that the PRCs are limited in their speed of innovation due to technology usage, probably resulting from high institutional dependency for managing research projects under rigorous guidelines, which limits the funds available for acquiring the latest technology for research, infrastructure, and hiring or training personnel. Despite these circumstances, the results indicate that PRC research

staff possess the skills to carry out effective technology transfer, having technological experience and market knowledge [156,157]. Therefore, it is extremely important that the PRCs increase their funds by obtaining resources derived from projects linked to different sectors.

Table 10. Pearson correlation of the scientific–technological collaboration TCs with the scientific production of PRCs during the period 2014–2019 in Mexico.

Laboratories		**Technology Transfers Concluded**	
Pearson correlation	0.310 *	Pearson correlation	0.194
Significance	0.032	Significance	0.186
JCR published articles		Graduate students	
Pearson correlation	0.050	Pearson correlation	0.15
Significance	0.734	Significance	0.308
Patent applications		Graduate programs	
Pearson correlation	−0.079	Pearson correlation	0.004
Significance	0.593	Significance	0.980
Patents granted		National research groups	
Pearson correlation	−0.004	Pearson correlation	−0.067
Significance	0.977	Significance	0.651
Book chapters		International research groups	
Pearson correlation	0.245	Pearson correlation	0.089
Significance	0.093	Significance	0.548
Books (published)		National thematic networks	
Pearson correlation	0.249	Pearson correlation	0.299 *
Significance	0.088	Significance	0.039
Utility model applications		International thematic networks	
Pearson correlation	−0.058	Pearson correlation	0.320 *
Significance	0.693	Significance	0.027
Utility models granted		Projects linked to industry	
Pearson correlation	−0.172	Pearson correlation	0.162
Significance	0.243	Significance	0.270
Trademarks registered		Projects linked to public services	
Pearson correlation	0.388 **	Pearson correlation	−0.047
Significance	0.006	Significance	0.753
Technology transfers in process		Projects by call	
Pearson Correlation	0.146	Pearson correlation	0.148
Significance	0.323	Significance	0.314

* the correlation is significant at the 0.05 level. ** the correlation is significant at the 0.01 level. These interactions were highlighted with the background color.

Regarding assimilation capabilities, TC 4 (use of knowledge) has a moderate correlation with the total number of book chapters (r = 0.328, p = 0.023) and the total number of published books (r = 0.313, p = 0.03). As this TC expresses the learning process through innovation-oriented interaction and is directly linked to the organization's speed of innovation [132,158,159], it should be better utilized by the PRCs since the results do not demonstrate its influence on other elements of scientific–academic productivity or knowledge transfer. It is worth mentioning that these results are evident according to the characteristics of the indicators. However, it is important for the PRCs to identify and analyze the causes and implement necessary actions to improve results.

On the other hand, TC 5 (research activities) has a moderate positive correlation with the total number of completed technology transfers (r = 0.326, p = 0.024) and the total

number of projects linked to industry (r = 0.312, p = 0.031). Similarly, TC 6 (technological validation) also has a moderate correlation with the total number of completed technological transfers (r = 0.352, p = 0.014) and the total number of projects linked to industry (r = 0.409, p = 0.004). Hsu and co-authors revealed that TCs related to R&D activities for new technological developments and products strengthen the relationship with market performance, which is confirmed through the results obtained about the effect of research activities and technological validation on elements of the PRC's scientific production directly related to the market [76].

6. Discussion

The latter denotes that these TCs are progressing well in the PRCs. However, they must be strengthened so that their influence is relevant to other important elements of scientific–academic productivity and knowledge transfer. Likewise, the results confirm that within the context in which the PRCs carry out research activities, these are relevant and have an effect on the productive sector.

The statistical analyses related to innovation capabilities showed that TC 7 (technological development) is moderately correlated with the total number of registered trademarks (r = 0.317, p = 0.028) and the total number of international thematic networks (r = 0.319, p = 0.027). These results indicate that the technological innovations developed in the PRCs have the potential to be commercialized, which is consistent with other findings about the market launch of new technologies and products as a result of this TC development [160]. Likewise, the results corroborate Haeussler et al.'s argument about the importance of this TC for the internationalization of organizations through strategic alliances, in this case, the participation of PRCs members in international thematic research networks [161]. On the other hand, the existing correlations with TC 8 (product development) correspond to the total number of concluded technological transfers (r = 0.309, p = 0.033) and the total number of projects linked to industry (r = 0.322, p = 0.026), and as can be seen, are moderate. These results reaffirm that product development capabilities are an important component of an organization's innovation process, and their primary goal is to provide innovative solutions to the market [83]. However, this differs from the results previously shown for technological development capabilities, as no relationship was found with elements of knowledge transfer, confirming that these capabilities, although important for the innovation process, are not enough to determine that such inventions entail a market transaction [83].

Regarding the support and linking capabilities, the results show that the existing correlations associated with TC 9 (technological services) are moderate and correspond to the total number of concluded technological transfers (r = 0.353, p = 0.014) and the total number of projects linked to industry (r = 0.319, p = 0.027). Similarly, these aspects of PRCs productivity are also moderately correlated with TC 10 (intellectual property usage) (r = 0.406, p = 0.004) and (r = 0.343, p = 0.017), respectively.

As mentioned above, about the TCs that allow for strengthening the relationship with the market [76], the results indicate that these capabilities denote an adequate level of development. However, efforts are required to have a greater effect on these results as well as on other elements related to knowledge transfer. Finally, the results of the analysis carried out on TC 11 (scientific–technological collaboration) indicate that it has a moderate correlation with the total number of laboratories (r = 0.310, p = 0.032), the total number of registered trademarks (r = 0.388, p = 0.006), and the total number of international thematic networks (r = 0.320, p = 0.027), while with the total number of national thematic networks, there is a weak correlation (r = 0.299, p = 0.039).

It is well known that the main benefit of scientific collaboration is the exchange of skills and knowledge between the parties. However, to obtain such benefits, actors need

to have a similar level of knowledge and capabilities so that through collaboration they can update and generate new knowledge [162,163]. The results obtained through the statistical analysis of TCs indicate that scientific–technological collaboration is related to the capabilities of technological development, product development, and intellectual property usage. However, as can be seen, the influence on the elements of scientific production is not relevant, which suggests special attention is needed in strengthening these capabilities in order to generate interest in collaboration with the Mexican PRCs by external actors. Through this study, it was possible to establish that the fostering of scientific–technological linkage represents a foundational technological capability for PRCs since it significantly enhances other technological capabilities through a multifaceted approach [164]. Firstly, it cultivates advanced skills among research staff by introducing new knowledge, refined techniques, and cutting-edge research methodologies. Secondly, it optimizes research infrastructure by providing access to state-of-the-art laboratories, equipment, and emerging technologies. Thirdly, it fosters a collaborative innovation environment that encourages interdisciplinary approaches and creativity. And finally, scientific–technological linkage serves as a catalyst for new funding opportunities and strengthens strategic partnerships, both domestically and internationally.

The link between academia and industry, and the development of innovative high-performance systems, are fundamental pillars of competitiveness and sustainable growth of any economy. Public research centers (PRCs) act as catalysts for this process, bridging the gap between the generation of knowledge and its industrial application. However, the effectiveness of this function depends on the strength and adaptability of their technological capabilities. By adopting a framework that allows them to identify, develop, and consolidate their current and future technological capabilities, PRCs can design strategies aligned with the needs of the productive sector, improve technology transfer, and, ultimately, boost national innovation. As a final point, we have acknowledged the challenge of generalizing findings across all the PRCs in Mexico. However, it is highlighted that the matrix developed in this study can serve as a foundational tool for assessing technological capabilities in PRCs of other developing countries with appropriate contextual adaptations. Additionally, it is recognized that there is a scarcity of existing literature on this topic and our work is positioned as a starting point for further research in this field.

7. Conclusions

Technological capabilities serve to enhance the different levels of performance of an organization and arise in response to its internal and external needs and stimulation. Through their measurement and analysis, it is possible to understand the technological platform on which the organization is performing and the results obtained under certain conditions of TCs development. This allows for more precise strategic planning and facilitates decision making when specifying the technological efforts to be made and the allocation of resources. The importance lies in detecting limitations, areas of improvement, and emerging opportunities. In Mexico, most PRCs do not carry out technological innovation because their TCs have not been fully developed, probably due to a lack of favorable economic conditions influencing infrastructure levels, resources for technology and R&D, competitiveness, and the country's development. Technological capabilities can, therefore, be used to evaluate the level of knowledge that is being generated and the type of research that may be susceptible to a technology transfer or the actions that must be taken to be competitive in innovation. However, by establishing a framework according to the PRC's context, it will be possible to measure and analyze TCs within PRCs to determine the required and viable efforts that allow them to raise the level of development of each TC. Among these efforts, opportunities for research collaboration with national and

international institutions should be considered, favoring the development of assimilation capabilities. Consequently, it becomes possible to develop other TCs and extend horizons for R&D, generating conditions for the technological innovation and competitiveness of the PRCs. Through the conducted study, the following conclusions are drawn in relation to the proposed hypotheses: Hypothesis 1: A positive correlation between the technological capabilities (TCs) of Mexican PRCs and their scientific output is confirmed, as evidenced by a significant volume of publications. However, most centers exhibit innovation and intellectual property TCs at the basic levels, limiting the potential impact of their research activities. Hypothesis 2: Both national and international collaborations positively influence the development of TCs. PRCs with active strategic alliances are mainly positioned at the intermediate levels of technological development, with some reaching advanced levels, highlighting the crucial role of these synergies in strengthening capacities. Hypothesis 3: PRCs with advanced TCs lead in intellectual property activities and, occasionally, technology transfer, demonstrating their impact on generating applied knowledge. However, most centers fail to reach optimal levels of development due to restrictive budgetary policies and government bureaucracy, limiting their global competitiveness.

In summary, the identification of TCs and their linkages with research activities provide a comprehensive framework for assessing the level of technological development. The main limitation of the investigation lies in the impossibility of extrapolating the results to all PRCs in the country. However, the presented matrix can be used as a basis for measuring TCs within science- and technology-based PRCs of developing countries. This study allows the development of new research, since, as mentioned initially, the literature on measuring technological capabilities within R&D institutions belonging to the public sector is scarce.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su17010122/s1, Questionnaire S1: Development of Technological Capabilities in Public Research Centers; Questionnaire S2: Scientific productivity.

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Institutional Review Board Statement: We would like to clarify that the research titled "Linkage Academia-Industry/Innovative high-performance systems: A pathway to strengthen technological capabilities for innovation in public research centers", although it involves the use of a survey, does not require approval from an ethics committee or institutional review board (IRB), for the following reasons:

1. Nature of the survey: The survey focuses on gathering information at the organizational level, specifically related to technological capabilities, infrastructure, and processes within organizations. The questions strictly address organizational aspects and do not seek personal opinions or behaviors, ensuring that no sensitive or personal data is involved.
2. Data collection and intervention: The study does not involve human or animal subjects, nor does it entail any biomedical, psychological, social, or behavioral science interventions. It exclusively focuses on assessing technological capabilities within organizations, specifically in areas such as infrastructure, organizational processes, and technological development.

3. Personal Data: The research does not collect any personally identifiable information from employees or other individuals. Al data collected pertains solely to the organizational level, without delving into personal or private matters.
4. The study does not involve or impact vulnerable populations, either directly or indirectly.
5. Risks: The research poses no risks to individuals, as it is based on the analysis of publicly available data regarding organizational technological capabilities. The data is organizational and sourced from public databases, ensuring that no activities compromise privacy or safety. The study does not evaluate individual performance and is limited to the collection and analysis of technical and operational data, intended purely for research and analysis purposes, without affecting employees or organizational decisions. The sole purpose of the study is to generate knowledge that can benefit society, and it adheres to ethical research principles.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data that support the findings of this study are available upon reasonable request.

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