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Proposal for a model to strengthen industry links for PhD programs in Engineering and Applied Sciences in developing countries

Eric Forcael[1]; Katherine Brintrup[2]
[1,2]Universidad San Sebastián, Chile, *eric.forcael@uss.cl, katherine.brintrup@uss.cl*

Abstract*– *Developing countries face the "middle-income trap," characterized by economic stagnation due to low technological sophistication and a critical disconnect between advanced human capital and the productive sector. In countries like Chile, this gap is evident: while 84% of PhDs work in academia, only 7% enter the business sector, contrasting with a University-Industry collaboration rate of 28% compared to the OECD average of 63%. This research proposes a strategic linkage model for doctoral programs in engineering and applied sciences to transform advanced knowledge into an engine of innovation and sustainable development. The methodology employs a qualitative exploratory approach in three phases: international benchmarking (Germany, Canada, and Australia), a situational diagnosis of the Chilean system, and validation through successful case studies based on Chilean PhDs in Engineering programs. The proposed model, aligned with the Education and Industry 5.0 paradigms, is structured around a Triple Helix governance (Government-University-Industry) and a dual curriculum that requires a 2-year industry internship with expert co-supervision. The results highlight the need to evolve accreditation criteria toward tangible impact indicators, such as non-academic employability, patent generation, and technology transfer at TRL 4-6 levels. In conclusion, this model bridges science and production, offering doctoral programs with sustainability and territorial relevance, helping countries overcome stagnation through innovation.

Keywords: University-Industry Linkage, PhD in Engineering, Applied Sciences, Developing Countries, Triple Helix.

I. Introduction

For decades, developing countries have faced a structural challenge known as the "middle-income trap," in which they experience rapid growth but fail to become developed nations [1]. Specifically, this situation is characterized by stagnant economic growth beyond a certain income level, hindering the transition to knowledge-based, innovation-driven economies. This trap stems largely from economic models centered on the extraction and export of raw materials, activities that demand little incorporation of advanced human capital and weak investment in sophisticated technologies [2]. This situation exacerbates the deficit in generating complex products and services with high-technology components, underscoring the importance of industrialization for sustained growth in developing countries. The above reveals the need to align the requirements of the productive and academic sectors, whose imbalance impedes integration between scientists and researchers from academia, who can positively influence the transfer and exchange of knowledge [3], and industry decision-makers.

In this context, the lack of articulation between higher education systems, particularly at advanced levels such as doctoral programs, and the productive sector has been identified as a critical barrier to the generation of knowledge with an impact on technological and industrial development. In Chile and other Latin American countries, this disconnect translates into limited participation of the industrial sector in the design and execution of doctoral research, as well as limited integration of PhDs into non-academic settings [4]. This situation undermines the country's capacity to generate innovative, technologically complex, and socially relevant solutions.

To address these systemic gaps, this research aims to design an effective linkage model between doctoral programs in engineering and applied sciences and the industrial sector in developing countries, such as those in Latin America, based on a comparative analysis of international best practices and the national quality assurance system. By transforming advanced human capital into an engine for sustainable technological development, this study seeks to strengthen the relevance and impact of doctoral training on national competitiveness. To establish a solid scientific and empirical foundation for this proposal, the following section reviews the literature on theoretical frameworks and international benchmarks that have successfully integrated doctoral research into the productive matrix.

II. Literature Review

The disconnect between advanced human capital and the productive sector in developing economies is often framed within the "middle-income trap." This phenomenon is not merely an economic stagnation but a failure to transition toward innovation-driven growth, largely due to a lack of integration between scientific research and industrial application.

A. Theoretical Framework: The Triple Helix and Beyond.

A substantial body of literature has framed innovation systems through the Triple Helix model [5]–[7], originally developed by Henry Etzkowitz and Loet Leydesdorff [8] at the end of the 20th century, which conceptualizes the dynamic interactions between University, Industry, and Government as the core drivers of knowledge-based economies. This model highlights the progressive blurring of institutional boundaries and the emergence of hybrid roles, where each sphere increasingly assumes functions traditionally associated with the others, fostering innovation through recursive and synergistic relationships [7]. Empirical studies have demonstrated the relevance of this framework across different contexts, showing how these interactions facilitate knowledge spillovers, technological transfer, and regional development, although with heterogeneous outcomes depending on institutional and national conditions [9]. At the same time, the limitations of the Triple Helix, particularly its abstract nature and insufficient consideration of contextual and societal factors, have motivated the evolution toward more comprehensive frameworks, such as the Quadruple and Quintuple Helix models, which incorporate civil society and the natural environment as additional dimensions of innovation systems, thereby enhancing their explanatory capacity in addressing sustainability and complex socio-technical challenges [10]. However, in emerging economies like Chile, these Triple Helix interactions often remain fragmented due to misaligned educational curricula and deficient coordination among actors. Therefore, it is imperative to design effective collaboration models within Triple Helix governance frameworks (Government-University-Industry) that enable advanced knowledge to be transformed into an engine of innovation, competitiveness, and sustainable economic development for the country [11], [12].

B. Economic Sophistication and the Need for Advanced Human Capital.

Economic and productive sophistication poses constant challenges for developing countries, where one of the critical barriers they must overcome is the low articulation between doctoral programs and the productive sector. In other words, these challenges are exacerbated by a severe disconnect between advanced human capital development and the productive sector. Evidence of this is that, while 84% of PhDs work in higher education institutions, only 7% enter the private sector, and University-Industry collaboration remains low, reaching only 28% in countries like Chile, a figure significantly lower than the OECD average of 63% [13]. In this sense, although the Chilean doctoral system has entered a phase of maturation and increasing complexity, current legal regulations and traditional accreditation criteria have tended to favor pure, disciplinary scientific research, limiting the formal recognition of more applied models or those directly linked to industry challenges.

In general, although some doctoral programs in engineering and applied sciences could boost industrial innovation, few actively promote structured University-Industry cooperation [14]. Often, doctoral research projects are developed independently of the needs of the national production sector, which significantly reduces their applicability and impact. At the same time, many companies do not strategically consider hiring PhDs, preferring immediate engineering solutions to investing in long-term R&D (Research & Development) capabilities, thus perpetuating the gap between science and production.

C. International Benchmarks and Paradigm Shifts as a Framework for the Proposed Model

To overcome productive stagnation in developing countries, it is necessary to examine successful international experiences that have contextualized doctoral training within the industrial environment [15]. Models in Germany, Canada, and Australia serve as benchmarks where tripartite governance (Government-University-Industry) and quality assurance frameworks validate results beyond scientific publication, such as patents and prototypes [16]. These systems demonstrate that industrial doctorates do not sacrifice scientific rigor; instead, they achieve strong sustainability and territorial relevance by positioning doctoral candidates as innovation mediators or triple helix workers [17]. In this context, the transition toward the Education 5.0 and Industry 5.0 paradigms aligns with this need, moving away from purely academic models to focus on practical educational relevance and the capacity to lead innovation processes that respond to real-world industrial challenges, based on the convergence of educational paradigms into Engineering Education 5.0 [18].

Thus, the proposed development of a model to strengthen industry ties for PhD programs in engineering and applied sciences in Chile, within the context of developing countries, addresses a national need and is fully aligned with the general objective of Research Paper No. 8 of the Chilean National Accreditation Commission (CNA): "To identify, describe, and analyze international best practices in collaborative doctoral programs with industrial partners, considering attributes of their quality assurance systems and comparatively situating this analysis within the national accreditation system in order to propose public policy initiatives for their future development" [15]. In other words, this research fully aligns with the general objective of the Chilean National Accreditation Commission [19], particularly its thematic focus on "Doctoral Programs and Industry Engagement," which promotes the study of the design of industry-oriented doctoral programs, the employability of PhDs outside academia, and the strengthening of the quality and relevance of these programs.

In summary, the need for this model stems from the fact that, while 84% of PhDs in countries like Chile work in academia, 60% express interest in migrating to the productive or public sector if the appropriate channels existed [13]. Accordingly, the objective of this research is to design an effective linkage model between doctoral programs in engineering and applied sciences and the industrial sector in Chile, based on the comparative analysis of international best practices and considering the attributes of the national quality assurance system, to strengthen the relevance, applicability, and impact of these programs on the development of the country.

III. METHODOLOGY

This research is based on a qualitative, exploratory-comprehensive approach designed to address the complexity of University-Industry partnerships in developing economies. The study moves beyond mere description to adopt an inductive and comparative content analysis design, focused on transferring and contextualizing successful international experiences within the national environment. The process was structured in three interdependent phases:

A. Phase I: Systematic Review and International Benchmarking.

In this initial stage, a meta-analysis of established doctoral models was conducted. To ensure a rigorous and traceable scope, the search was conducted across international databases (WoS, Scopus, and SciELO) and official government repositories, using keywords such as "Industrial PhD," "Professional Doctorate," and "Triple Helix Governance." Germany, Canada, and Australia were selected as benchmarks due to their track records in industrial doctoral programs. The selection criteria included:

- <u>Timeframe</u>: Recent evidence (2021-2025) that captures the shift to Industry 5.0 and Education 5.0.

- Critical Dimensions: The mechanisms of tripartite governance (Government-University-Industry) and quality assurance frameworks that validate results beyond scientific publication, such as patents and prototypes, were specifically examined.
- Categorization: A document analysis matrix was used to systematize public policies, curricular structures, and graduate profiles in eight leading countries initially identified; the final selection was narrowed to three based on the existence of specific national industrial PhD funding policies.

B. Phase II: Situational Diagnosis of the Chilean Doctoral System.

To substantiate the need for the model in the local context, an exploratory diagnosis was carried out following a sequence of four stages:

- Data Collection: Official sources from the Higher Education Information Service (SIES) and formal statements of graduate profiles on institutional websites were used. The scope included the entire universe of accredited Engineering PhD programs in Chile as of 2024 to ensure statistical representativeness.
- Operational Classification: A conceptual proposal was developed to distinguish between academic, professional, and industrial doctorates, challenging the single legal definition currently in force in Chile.
- Automated Content Analysis: A keyword search algorithm (e.g., “applied innovation,” “technology transfer,” “problem solving”) was applied to program descriptions to identify predominant discursive orientations. This procedure followed an inductive coding approach, where categories were derived from the textual data to minimize researcher bias.
- Case Study Testing: The research was validated through an in-depth analysis of 19 Chilean accredited programs, such as the PhD in Engineering and Science with Industry program (Pontifical Catholic University of Chile), the PhD in Applied Engineering program (Federico Santa María Technical University), and the PhD in Mineral Processing Engineering program (University of Antofagasta).

C. Phase III: Structural Design and Model Validation

Based on the thematic triangulation of international best practices (Phase I) and the gaps identified in the national diagnosis (Phase II), the model architecture was designed. This phase consisted of:

- Definition of Dimensions: The model was structured around four fundamental axes: Curriculum and Training, Collaboration, Quality Assurance, and Governance.
- Regulatory Alignment: The guidelines of the National Accreditation Commission (CNA) were integrated, proposing a shift from simply counting publications to indicators of tangible impact and non-academic employability.
- Flow Validation: A bidirectional cycle was established, comprising stages of diagnosing territorial gaps, collaborative implementation with a physical presence in Industry for at least two years, and effective transfer of results with economic impact.

This methodology guarantees the traceability of the process and ensures that the proposal is not merely a replication, but rather an articulated system capable of transforming advanced human capital into an engine of sustainable technological development for the country.

IV. Results

The University-Industry Linkage (UIL) Model for Doctoral Programs in Engineering and Applied Sciences proposed in this research is based on the need to overcome the “middle-income trap,” present in developing economies mainly, and characterized by low technological sophistication and stagnant productivity, which demands structural integration between advanced human capital (higher education institutions) and the productive sector (Industry).

The proposed model is grounded in the paradigms of Education 5.0 and Industry 5.0, which transcend mere technological efficiency to incorporate critical thinking, creativity, and social impact, placing the person at the center [18]. Therefore, it moves away from the purely academic doctoral model to focus on practical educational relevance, aligning research with the country’s real-world challenges. The dimensions of the proposed model are detailed below and summarized in Table I.

TABLE I
DESCRIPTION OF THE DIMENSIONS AND COMPONENTS OF THE PROPOSED GOVERNANCE MODEL BETWEEN THE UNIVERSITY, INDUSTRY, AND GOVERNMENT.

Dimension	Key Components	Objective and Expected Impact
Curriculum	Dual research, thesis in a company, and a graduate profile validated by the Industry.	To ensure the relevance of the training and the immediate applicability of the results.
Collaboration	Industrial co-management, shared infrastructure, and intellectual property management.	To strengthen the Research, Development, and Innovation (R+D+i) ecosystem and facilitate effective technology transfer.
Quality	Indicators of non-academic employability and measurable economic impact.	To comply with CNA standards and ensure continuous improvement of the program.
Governance	Tripartite relationship (Government-University-Industry) and active internationalization.	To achieve the model’s sustainability and overcome the “middle-income trap”.

A. Curricular and Training Dimension

The first dimension to be considered is related to the curriculum and training of the program, according to the following aspects:

- Dual and Applied Research: The program’s structure allows students to conduct their research directly within Industry, addressing real-world problems with academic support. Specifically, the last 2 years of training must be completed in person at a company, institution, or technology center.
- Transversal Competencies: The curriculum must integrate training in innovation, intellectual property, technology management, and applied research

methodologies. This aspect prepares the doctoral candidate not only as a researcher but also as a leader of innovation processes capable of managing complex projects.

- Validated Graduate Profile: The profile must be defined and validated bidirectionally by academia and key industry stakeholders to ensure its alignment with global and local needs. This profile validation must also be aligned with the government's needs and projections.

B. Collaboration Dimension

The second dimension to be part of the proposed doctoral program is related to the collaboration between all the participants of the academic process (students, professors, external professionals, and mentors), according to the following aspects:

- Co-supervision of Theses: To improve the interaction between students and their environment, it is crucial to involve industry professionals in defining thesis topics and in the shared supervision (co-supervision) of doctoral candidates.
- Access to Infrastructure: Given the importance of practical and laboratory activities in doctoral training, it is essential to foster formal collaboration schemes that enable the shared use of university laboratories and industrial facilities for co-designing technological solutions.
- Internationalization: In a hyper-connected world, it is impossible to imagine a model in which professors and doctoral students do not have strong international networks. For this reason, it is essential to foster networks with foreign institutions that have established models of industrial doctorates, integrating international experts in the validation of training processes.

C. Quality Assurance Dimension

Whether viewed from an internal perspective (within the doctoral program itself) or an external one (such as government agencies), quality assurance is one of the most important considerations when building a doctoral program. Accordingly, the following are some aspects to consider from a quality perspective.

- Impact Indicators: Evolution of accreditation criteria to include metrics that are not always analyzed, such as the employability outside academia, along with effective technological transfer (licenses, patents, prototypes), and tangible contribution to economic development.
- Verification: The model must be sustainable and measurable, going beyond standard indicators such as "number of theses", "number of published papers in indexed journals", or "years to complete the program", through systemic linkage strategies.

D. Governance Dimension: The Triple Helix Model

In terms of governance, the triple helix approach plays a crucial role, with a University-Industry-Government framework established as part of the proposal model and responsibilities shared among the parties.

The University-Industry-Government triple helix model promotes innovation and entrepreneurship by leveraging hybrid organizations such as technology transfer offices, venture capital firms, incubators, accelerators, and science parks to help various stakeholders understand their regional roles [12]. From this perspective, Muchsam *et al.* [20] note that emerging economies (e.g., Indonesia, Chile, etc.) face structural barriers, including misaligned educational curricula, fragmented labor information systems, and deficient coordination among triple-helix actors. Thus, to improve competitiveness, integrating talent intelligence with collaborative governance is key, and this requires university-business collaboration, especially through doctoral programs in engineering and applied sciences.

In this context, the government acts as a facilitator through financial initiatives, implementing more flexible regulations to facilitate the integration of researchers into companies, and strengthening the R+D+i ecosystem by linking the Undersecretariat of Higher Education with development agencies such as CORFO (Chilean Production Development Corporation, in charge of promoting innovation, entrepreneurship, and investment across various industries). These initiatives should include, for example, collaborative working groups to identify issues in the country's productive sector, funding to support student internships in the industry, and, especially, the creation of a dedicated fund to partially finance the hiring of PhDs across business sectors that are strategic to the country.

E. Validation of the Model through National Evidence and Reference Cases

The proposed model is based on successful pilot initiatives in Chile. Its transition from theory to practice is validated by evaluating Chilean PhD programs that demonstrate the dimensions outlined in Table I.

1) Empirical Evidence of Curricular Viability: The PhD in Engineering at the Pontifical Catholic University of Chile shows that the dual research structure works. Pilot data indicate that doctoral candidates can maintain scientific rigor while spending 2 years in the industry. The "training triad" (university-student-partner) is effective, as evidenced by technological solutions that impact the industry beyond just scientific publications.

2) Validation of Impact Indicators: The empirical findings show that industrial link models lead to tangible outcomes. For example, Chile's PhD programs in Applied Engineering and Mineral Processing Engineering have documented patents, utility models, and technology packages at TRL levels 4-6 through industrial co-supervision. While the average PhD private-sector employment rate is 7%, the reviewed programs show a much higher non-academic employment rate, with 60% of students aiming to enter the productive sector, as reflected in outcomes such as patents.

3) Governance and Sustainability: The analysis of the Chilean "Engineering 2030" consortium offers an empirical basis for the Governance dimension, showing that academic commitment alone is inadequate. Sustainability needs shared governance and flexible protocols to bridge the cultural gap between industry and academia.

Thus, the proposed model, based on the triple helix approach, is graphically presented in Fig. 1.

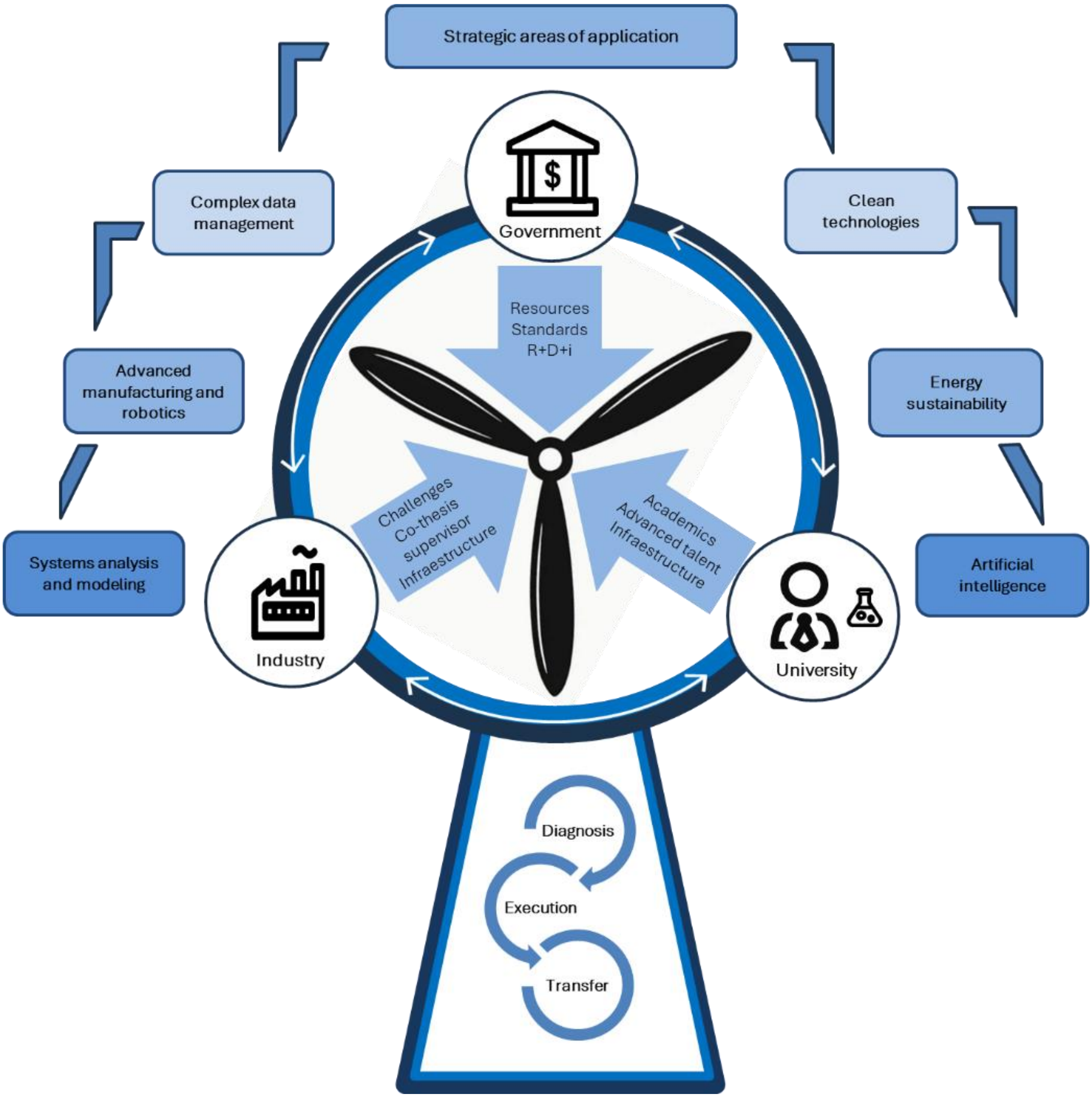

Figure 1. Tripartite Governance Scheme between the Government, University, and Industry.

The university provides scientific rigor, academic and methodological support, and infrastructure, creating advanced human capital to ensure certifications and quality processes in the industrial sector. The industry defines strategic challenges, generating real-world problems to solve within research areas, using specialized infrastructure, and is co-directed by technical experts for a minimum of 2 years. This approach fosters employability in the industry. This shared governance is essential to mitigate the short-term vision that often prevails in the national private sector.

The proposed model seeks to transform the PhD in engineering and the PhD in applied sciences from a "classroom and laboratory researcher" into a driver of technological and economic development, with a focus on applied and industrial research.

E. Implementation Flow

The implementation flow and strategic areas constitute the operational and thematic phase of the model, specifically designed to transform advanced knowledge into concrete solutions that enable developing countries to overcome productive stagnation.

These two key components are explored in greater detail below:

1. Implementation Flow:

- <u>A Bidirectional Cycle</u>: The model does not operate linearly, but rather as a cycle of three interconnected stages that ensure constant feedback between academia, the productive sector, and regulatory standards.
- <u>Diagnostic and Alignment Phase</u>: In this initial stage, direct consultations are held with companies and public development agencies, such as CORFO and ANID (Chilean government agency responsible for managing, promoting, and financing scientific research, technological development, and innovation). The goal is to identify technological gaps and priority areas where the government and industry require high-level

innovation. This approach ensures that doctoral research is not developed in isolation from the national context, but rather responds to the country's strategic needs.

- Collaborative Execution Phase: This stage is the core of the training process, where the dissertation is developed under a shared governance framework. Here, the dual curriculum structure requires doctoral students to spend at least 2 years physically at the company or technology center. During this time, they benefit from joint academic and industrial supervision, facilitating knowledge exchange and access to specialized industry technical infrastructure.
- Transfer and Impact Phase: This phase culminates in the generation of complex products, patents, or licenses that are directly integrated into the production sector. A key differentiator is that this outcome not only benefits the company but also closes the loop by feeding into the quality assurance system (CNA). The economic impact and non-academic employability are evaluated, allowing for adjustments to the programs for continuous improvement.

2. Strategic Areas of Application

To maximize the impact on the production matrix, the model prioritizes sectors with high capacity for technological sophistication and economic transformation:

- Clean technologies and energy sustainability: Focused on the transition to more sustainable and efficient production models.
- Artificial Intelligence (AI) and complex data management: A critical area for process modernization and evidence-based decision-making in Industry 5.0.
- Advanced manufacturing and robotics: Aims to increase the complexity of locally produced goods, reducing dependence on the export of basic raw materials.
- Analysis and modeling of complex systems: Essential for addressing multidisciplinary industrial problems that require high-level abstraction and scientific rigor.

The selection of these areas and the rigor of the implementation process aim to mitigate the private sector's short-term vision, proving that advanced human capital is the primary asset for modern, sustainable industrialization.

To clarify the implementation, the model distributes responsibilities as detailed in Table II.

TABLE II
FUNCTIONS AND RESPONSIBILITIES OF THE PROPOSED GOVERNANCE MODEL AMONG THE UNIVERSITY, THE INDUSTRIAL AND PRODUCTIVE SECTOR, AND THE GOVERNMENT.

Actor	Role in the Model	Main Contribution
University	Academic and methodological support.	Scientific rigor, advanced training, and quality certification.
Industry	Application and validation environment.	Real challenges, technical infrastructure, and expert co-direction.
Government	Facilitator and regulator.	Financial incentives (CORFO, ANID), regulatory frameworks, and quality standards (CNA).

V. DISCUSSION

The implementation of a Middle-Income Development Model (MIDM) in developing countries represents a strategic and necessary response to overcome the "middle-income trap" [1]–[3], [21]. While traditional models have focused on growth based on the exploitation of raw materials, this model proposes a transition to a knowledge economy through the development of advanced human capital directly integrated into the productive sector [14], [22]–[25].

Although the Triple Helix model has been widely applied to foster innovation systems, its implementation in doctoral education, particularly in developing countries, remains fragmented, with limited evidence on structured models that effectively integrate the industry within PhD programs [6], [7].

Unlike traditional doctoral programs, which are more focused on scientific productivity measured in publications, the proposed model prioritizes relevant training and applied research [14], [15], [26]. The integration of Education 5.0 and Industry 5.0 paradigms allows doctoral students not only to generate knowledge but also to lead innovation processes with a strong ethical, creative, and social component. This vision aligns with the need to evolve from conventional engineering solutions toward doctoral-level innovations that have a structural impact on business productivity [14], [15], [27].

A critical aspect discussed is the need for quality assurance systems, such as those of the CNA in Chile, to evolve [14], [15], [28]. Current indicators are often insufficient to assess actual engagement; therefore, the model suggests moving toward metrics that consider employability outside academia, the development of complex products, and effective technology transfer. International evidence suggests that accredited programs with a strong industry orientation facilitate the shift from theory to practice, closing the historical gap between science and production [3], [14], [15], [21], [29]–[34].

The experience of the Chilean university consortium Engineering 2030 shows that academic commitment alone is insufficient without flexible administrative protocols and effective communication channels [14]. The main barriers identified include a cultural disconnect, as the industry often fails to recognize the value of a PhD, preferring immediate solutions to long-term R&D investment [15]. Institutional coordination, particularly due to disparities in administrative procedures among universities, can hinder the smooth operation of a dual program. Academics and students must participate in business events and technology fairs, not just scientific conferences, to foster a shared culture of innovation [14], [15].

Pilot programs such as the DICI Program at the Pontifical Catholic University of Chile demonstrate that it is possible to operationalize this linkage through a "training triad" (university-student-partner organization) and mandatory external co-supervision schemes. However, the sustainability of these models faces the challenge of the inadequacy of the regulatory framework and quality metrics of the National Accreditation Commission (CNA) and ANID. For applied research to be viable, the quality assurance system must evolve from counting WoS publications to indicators of tangible impact, such as the generation of patents, utility models, technology packages, and the effective integration of PhDs into industrial leadership positions. Finally, international discussions (cases from Australia, Spain, and Brazil) underscore that these programs should not be considered less rigorous, but rather as having "strong sustainability" and territorial relevance, where the doctoral candidate acts as an innovation mediator or "triple helix worker." Therefore, the proposed model requires governance where the Government acts as a facilitator through specific financial incentives, such as industrial PhD scholarships, and regulatory frameworks that formally recognize practice-based research as a strategic asset for national development [16].

The substantiation of this model's impact lies in its departure from traditional "linear" innovation (from the University to the Industry) toward a "recursive" Triple Helix model (Government-University-Industry). Unlike traditional PhDs, where the academic is the sole evaluator, this model's success is validated by its "territorial relevance"; the degree to which a doctoral thesis solves a specific industrial bottleneck. By shifting the quality metric from "WoS publications" to "non-academic employability" and "patent generation," the model creates a market incentive for companies to invest in PhDs. This challenging approach is the mechanism that will shift private-sector employment of PhDs from the current 7% in developing countries like Chile toward the OECD average of 63%, effectively dismantling the barriers to sophisticated industrialization.

Finally, the sustainability of this model depends on effective tripartite governance. The Government must act not only as a funder through agencies such as CORFO or ANID, but also as a regulatory facilitator that incentivizes the integration of researchers into the industry [15], [31], [35]. The creation of doctoral programs that allow students to develop their theses physically in the industry with exclusive dedication is emerging as a key differentiator in transforming the productive matrix in developing regions [14], [35]. It is imperative to move towards metrics that recognize employability outside academia, the development of complex products, the generation of patents and licenses, and the tangible contribution to economic development [14], [15], [28], [31], [36]. Only if the accreditation system values and rewards this connection can doctoral programs in engineering and applied sciences consolidate themselves as true engines of productive modernization [15].

VI. CONCLUSIONS

The transition of developing countries to knowledge-based economies demands a paradigm shift in the training of advanced human capital. The MVDI (Drug Management and Innovation Model) proposed in this research is presented as a strategic tool to overcome the "middle-income trap," transforming doctoral programs in engineering and applied sciences from centers of academic scientific production into engines of technological and economic sophistication.

The effectiveness of this linkage depends on a dual curricular structure in which research stems not only from scientific curiosity but also from real-world challenges in the productive sector. The proposed model ensures this relevance by stipulating that the final two years of training take place in an industrial setting, guaranteeing immediate bidirectional knowledge transfer.

The model transcends Industry 4.0's technical efficiency to integrate the values of Education 5.0, fostering a graduate profile characterized by critical thinking, ethics, and the ability to lead complex innovation processes that generate social value and promote energy sustainability. It is important to consider that the viability of this model rests on a strong alliance among the University, Industry, and the Government. While the University contributes methodological rigor, Industry must commit to integrating PhDs into its strategic decision-making processes, and the Government must act as a facilitator through regulatory incentives and specific development funds.

It is imperative that accreditation systems, such as the CNA in Chile, incorporate new quality indicators that value non-academic employability, patent generation, and tangible impact on national productivity. Measuring the number of Theses is insufficient; it is necessary to verify effective job placement and the creation of complex technological solutions.

In summary, the developed model provides a concrete roadmap for strengthening the R+D+i ecosystem. By aligning doctoral training with the country's strategic needs, it lays the foundation for modern industrialization and sustained economic growth, making advanced knowledge the primary asset for national development.

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