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Effective Model of Knowledge-Based Transformation and Sustainable Development in BRICS-T Countries

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Abstract

This article presents a novel empirical framework for evaluating knowledge-based transformation and sustainable development in BRICS-T countries. The framework is based on an integrated Triple Helix assessment model that quantifies the interrelationships between research output, educational innovation, industry engagement, market alignment and policy support. Using a comprehensive dataset from 60 universities across BRICS-T countries, combined with an AHP-based weighting system derived from 24 cross-sector experts, this study reveals previously unidentified patterns in innovation and educational outcomes. Our method demonstrates that only research output (β = 0.375, $p < 0.001$) and industry engagement (β = 0.418, $p < 0.001$) consistently predict innovation output across all BRICS-T countries, while market alignment influences educational quality in only four out of the six nations. The analytical framework successfully quantifies significant performance variations across countries, with innovation output scores ranging from 2.89 to 4.23 and educational quality scores ranging from 3.08 to 4.15. The findings contribute to Triple Helix theory through country-specific decomposition of relationships, supplementing existing knowledge-based economy theories with quantitative evidence of differential effectiveness across emerging economies. This methodology can be implemented for strategic planning in higher education systems transitioning from resource-based to knowledge-based economies.

Keywords:

Triple Helix Model; BRICS-T Countries; Innovation Output; Educational Quality; University-Industry Collaboration; Knowledge-based Economy; Research Output; Cross-Country Analysis; Resource-based Economy; Development Challenges.

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1- Introduction

BRICS-T countries face significant challenges in transitioning from resource-to knowledge-based economies, particularly in terms of developing effective innovation systems and quality education [1]. These emerging economies

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have historically relied on natural resources and low-cost manufacturing for economic growth, a model that has demonstrated both vulnerability and strategic advantages in the global economy [2]. Although resource dependence can create economic volatility and environmental challenges [3], recent global energy market disruptions have demonstrated how resource wealth can be leveraged for economic and geopolitical advancements [4]. However, sustainable long-term development still requires diversification toward knowledge-intensive sectors [5, 6]. Despite their rapid economic growth, these countries struggle with institutional inefficiency, inadequate research infrastructure, and gaps between educational outcomes and market needs [7]. The persistent challenge of developing high-quality education systems that can support knowledge-based economic development is particularly concerning.

The United Nations Sustainable Development Goal 4 emphasizes the crucial importance of quality education in achieving sustainable development, with specific targets focusing on higher education quality and its relevance to economic needs [8]. This goal has varying degrees of relevance across the BRICS-T countries, with significant disparities in educational development among the member states [9]. Although China has achieved remarkable progress in educational quality and innovation capacity [10], other BRICS-T members face ongoing challenges in aligning their education systems with the knowledge economy requirements [11]. These intersystem differences are particularly evident in areas such as research output, technological readiness, and industry-academia alignment [12]. Improving education quality is fundamental to achieving sustainable development and successful transition to knowledge-based economies in emerging markets [13].

The literature on innovation and education quality in emerging economies has developed through multiple research streams that address different aspects of development challenges. Hamdan & Alsuqaih [14] analyzed research output metrics in the social sciences during COVID-19, examining productivity, visibility, and collaboration patterns through scientometric analysis, while Al-Jamimi et al. [15] reviewed bibliometric indicators for research evaluation, specifically in emerging market economies, addressing their unique measurement challenges. Dang et al. [16] investigated university-industry knowledge collaborations in Vietnam, analyzing their outcomes and effectiveness, complemented by Passos et al. [17], who systematically reviewed the literature on university-industry collaboration processes to identify key success factors and challenges. Policy-focused research includes work by Ordóñez-Matamoros et al. [18], examining transformative innovation policy in emerging economies; Schot & Steinmueller [19], who proposed three distinct frames for innovation policy (R&D, systems of innovation, and transformative change); and Rababah et al. [20], who studied university social responsibility during COVID-19 in BRICS countries. Pradhan et al. [21] investigated the relationship between innovation, institutional quality, and economic growth in developing countries, while Semenova et al. [22] and Andonovikj et al. [23] explored the infrastructural role of education in emerging markets and data-driven approaches to align academic offerings with industry needs.

Recent research has increasingly focused on technological dimensions, with Belli & Magalhães [24] examining digital transformation within BRICS countries and its relationship with digital sovereignty, revealing how these nations leverage technological advancements to construct more autonomous digital ecosystems. Similarly, Ma & Zhu [25] investigated innovation in emerging economies, specifically through the lens of the digital economy’s role in driving high-quality green development, demonstrating how digital technologies can simultaneously advance economic growth and environmental sustainability goals. These studies represent the cutting-edge of research examining how digitalization and technological readiness reshape innovation capabilities in emerging economies, particularly highlighting the dual potential of digital transformation to address both economic and environmental challenges.

While prior research offers valuable insights into specific aspects of innovation and educational quality, these studies typically examine factors in isolation rather than consider their interdependence. The literature has generally taken a compartmentalized approach: Temel et al. [26] focused narrowly on university innovation intermediaries and patenting performance without addressing broader ecosystem connections; Terra et al. [27] examined entrepreneurial universities in Brazil from a limited perspective that does not fully consider cross-sector interactions; and Yang et al. [28] studied policy factors such as remittance inflows in BICS countries without integrating educational or innovation dimensions. This siloed approach extends to geographic scope limitations, with Thakur-Wernz & Bosse [29] analyzing emerging economy firms’ learning conduits without sufficient cross-country comparison, while Cooke [30] focuses specifically on China’s HRM and employment practices without comparative analysis across emerging economies. Even when comparative elements exist, studies such as Thomas et al. [12] and Robertson et al. [31] focus on limited indicators or specific institutional aspects rather than comprehensive systemic interactions.

This fragmented research landscape has created a significant knowledge gap in our understanding of how institutional factors collectively shape innovation and educational outcomes in emerging economies. The literature lacks integrated frameworks that can simultaneously capture the complex relationships among university performance, industry engagement and policy effectiveness across different national contexts. This gap is particularly pronounced for BRICS-T countries, which, despite sharing common development challenges such as transitioning from resource-based to knowledge-based economies, operate under distinctly different institutional arrangements that influence how innovation ecosystems function. Without research that examines these interrelated factors together, our understanding remains incomplete regarding how varying institutional configurations affect innovation output and education quality across these important emerging economies, limiting our ability to develop context-appropriate policy recommendations for knowledge-based transformation.

The present study addresses this gap by investigating the effectiveness of university-industry-government relationships in fostering innovation and education quality across emerging economies. To this end, this study employs the Triple Helix model, which provides a theoretical framework for understanding how interactions between universities, industry, and government contribute to innovation and knowledge-based development [32]. The Triple Helix model is particularly appropriate for this investigation because it captures the dynamic relationships between key institutional actors and their collective role in driving innovation and educational outcomes.

Despite recent studies examining digitalization [24], technological readiness [25], and institutional quality [21] in BRICS-T countries, research on the collective dynamics of innovation and education systems remains underdeveloped. This gap in the understanding of the integrated Triple Helix relationships in BRICS-T contexts necessitates a more systematic investigation.

This study makes significant contributions by providing a comprehensive understanding of the barriers and facilitators of innovation and educational quality in BRICS-T countries. The model identifies specific areas in which institutional relationships are effective or lacking, offering valuable insights for policymakers and institutional leaders working to enhance innovation capabilities and education quality in emerging economies. The findings help explain why certain theoretically important relationships may not function as expected in emerging economic contexts, contributing to both theoretical understanding and practical policy development.

2- Literature Review

2-1- Global Shift toward Knowledge-Based Economies

Knowledge-based economies have emerged as the dominant economic paradigm in developed nations, characterized by an emphasis on intellectual capabilities rather than physical inputs or natural resources [33]. This transition has been driven by recognition that a sustainable competitive advantage in the modern global economy stems from innovation, technological advancement, and human capital development. Developed countries have successfully leveraged knowledge-intensive industries, created higher-value economic activities, and maintained economic growth while reducing environmental impact [34]. Developing countries are increasingly pursuing this economic model as traditional resource-based growth becomes less sustainable and competitive in the global marketplace.

The relationship between sustainable development and knowledge-based economies is increasingly recognized as symbiotic. Knowledge-based economies typically demonstrate lower environmental impacts while generating higher economic value, which aligns with sustainable development goals [35]. Research has shown that countries with knowledge-intensive economies are better positioned to develop and implement sustainable technologies, practices, and policies [36]. Moreover, an emphasis on human capital development in knowledge-based economies supports social sustainability through improved education, healthcare, and quality of life.

Resource-based economies offer certain advantages, such as immediate natural resource revenues and lower initial investment requirements, but face significant limitations and challenges. These economies often struggle with resource depletion, environmental degradation, and economic volatility because of commodity price fluctuations [37]. By contrast, knowledge-based economies offer more sustainable growth patterns, greater economic resilience, and higher value-added activities. However, the transition from resource-to knowledge-based economies requires substantial investments in education, research infrastructure, and institutional development [37].

2-2- BRICS-T: Challenges in Transitioning to Knowledge Economies

The concept of BRICS emerged in 2001 when economist Jim O'Neill of Goldman Sachs identified Brazil, Russia, India, and China as emerging economies with significant potential for global economic impact [38]. South Africa joined the group in 2010, and Türkiye's increasing economic significance and strategic position led to its consideration as part of this bloc of emerging economies, forming BRICS-T. These nations are grouped together because of their shared characteristics: large populations, vast territories, substantial natural resources, and rapidly growing economies. The formation of this alliance was driven by these countries' desire to challenge the existing global economic order and establish a more multipolar world economy, particularly in the aftermath of the 2008 global financial crisis [39]. Over the past two decades, BRICS-T countries have strengthened their cooperation through various initiatives, including the New Development Bank and regular summit meetings, aiming to enhance their collective influence on global economic governance [40].

BRICS-T countries have emerged as significant players in the global economy, collectively representing approximately 42% of the world's population and 24% of the global GDP [41]. These nations formed alliances on the basis of their shared characteristics as large, rapidly developing economies with significant resource endowments and growing global influence. Despite their economic progress, these countries face common challenges in transitioning from resource-to knowledge-based economies, including institutional weaknesses, technological gaps, and human capital limitations [42]. While China has made substantial progress in developing its innovation capabilities and knowledge economy, other BRICS-T nations still rely heavily on natural resources and low-cost manufacturing, making them vulnerable to global market fluctuations and economic instability [5].

The transition of BRICS-T countries toward knowledge-based economies is intrinsically linked to their human resource development and quality of education. Recent studies indicate that despite significant investments in education, countries still face substantial challenges in developing skilled workforces necessary for knowledge-intensive industries [18]. The gap between current educational outcomes and the requirements of a knowledge-based economy remains a critical barrier to economic transformation. According to Şenturk & Ali [43], while BRICS-T countries have made progress in expanding access to education, they still lag behind developed nations in terms of educational quality, research output, and innovation capabilities. This educational quality gap not only hinders their progress toward SDG 4 but also impedes their ability to compete effectively in knowledge-intensive global markets [44].

2-3- Applying the Triple Helix Framework to BRICS-T Economic Development

The literature suggests several key approaches to facilitating transition to knowledge-based economies. These include strengthening education systems, particularly higher education and research capabilities [45]; developing innovation ecosystems through industry-academia collaboration [46]; and implementing supportive policy frameworks [47]. Recent studies have emphasized the importance of institutional capacity building and the development of appropriate governance structures to support knowledge-based economic activities [48].

Although these approaches identify crucial elements for economic transition, there remains a need for an integrated framework that can effectively capture the complex interactions between these elements. This need is particularly important given that a successful transition to a knowledge-based economy requires coordinated action from multiple stakeholders. The Triple Helix model addresses this need by providing a comprehensive framework for understanding these complex interactions. Developed by Leydesdorff & Etzkowitz [49], this model provides a comprehensive framework for understanding the interactions among universities, industry, and government in fostering innovation and knowledge-based development. The model identifies several key variables: Research Output (measuring academic research productivity and impact), Educational Innovation (capturing novel teaching and learning approaches), Industry Engagement (reflecting university-industry collaboration intensity), Market Alignment (indicating the match between educational offerings and market needs), and Policy Support (measuring governmental facilitation of innovation) [49]. Therefore, this study uses this model to capture the complex interrelationships necessary for a successful transition to a knowledge-based economy while providing measurable variables for assessing progress and identifying areas for improvement.

2-4- Study Hypotheses

Research output (RO) plays a crucial role in driving innovation and educational outcomes in knowledge-based economies. Universities' research activities generate new knowledge, technologies and methodologies that can be transformed into innovative products and processes [50]. Studies have shown that strong research output correlates with increased patent applications, technological breakthroughs, and commercial innovation [51]. Furthermore, research activities enhance the quality of education by incorporating cutting-edge knowledge into curricula and by exposing students to advanced methodologies and techniques. Based on these arguments, this study hypothesizes that research output positively influences innovation output and educational quality:

H1: Research Output has a positive influence on innovation output in BRICS-T universities.

H2: Research Output positively affects Educational Quality in BRICS-T universities.

Educational innovation (EI) refers to universities' capacity to develop and implement novel teaching methods, learning technologies and educational approaches. As educational systems evolve to meet the demands of knowledge-based economies, educational innovation has become increasingly crucial for innovation output and educational quality [52]. Innovative educational practices can foster creative thinking and problem-solving skills essential for innovation while simultaneously enhancing learning outcomes and educational effectiveness [53]. Previous research has demonstrated that universities with higher levels of educational innovation tend to produce more innovative graduates and achieve better educational outcomes [54]. Therefore, it is proposed that educational innovation positively affects both innovation output and educational quality:

H3: Educational Innovation has a positive influence on innovation output in BRICS-T universities.

H4: Educational Innovation positively affects Educational Quality in BRICS-T universities.

Industry engagement (IE) represents the extent of university–industry collaboration. Strong university-industry linkages facilitate knowledge transfer, provide real-world application opportunities, and align academic research with market needs [55]. Higher levels of industry engagement lead to increased commercialization of research outputs and more practical innovations [56]. In addition, industry engagement enhances educational quality by providing students with practical experience, industry exposure, and relevant skill development opportunities [57]. Thus, the following hypotheses convey that industry engagement positively influences innovation output and educational quality:

H5: Industry Engagement has a positive influence on innovation output in BRICS-T universities.

H6: Industry Engagement positively affects Educational Quality in BRICS-T universities.

Market alignment (MA) reflects how well university programs and research align with market and industry requirements. Strong market alignment ensures that educational offerings remain relevant and that research activities address practical challenges [58]. Studies have demonstrated that universities with better market alignment tend to produce more commercially viable innovations and maintain higher educational quality standards [59]. When educational programs are well-aligned with market needs, innovation capacity and educational effectiveness are enhanced. Therefore, it is hypothesized that market alignment positively affects innovation output and educational quality:

H7: Market Alignment has a positive influence on innovation output in BRICS-T universities.

H8: Market Alignment positively affects Educational Quality in BRICS-T universities.

Policy support (PS) encompasses governmental initiatives, regulations, and support mechanisms that facilitate university-industry collaboration and knowledge-based development. Effective policy support can create favorable conditions for innovation by providing resources, incentives, and institutional frameworks [60]. Research has revealed that strong policy support correlates with increased innovation output and improved educational quality across different contexts [61]. Policy measures can enhance universities' innovative capacity and quality of education through funding, regulations, and institutional support. Based on these arguments, it is hypothesized that policy support positively influences innovation output and educational quality.

H9: Policy Support has a positive influence on innovation output in BRICS-T universities.

H10: Policy Support positively affects Educational Quality in BRICS-T universities.

3- Material and Methods

The research methodology, as illustrated in Figure 1, follows a structured process, beginning with a literature review and hypothesis development, followed by model variable definition. The methodology then branches into two parallel tracks: an expert assessment pathway using 24 experts through AHP-based weight calculation and a data collection pathway gathering information from 60 universities across -T countries. These pathways converge at the composite score calculation stage, where expert-derived weights are applied to normalized university data. The final stage employs multiple regression analysis to test the hypothesized relationships between Triple Helix variables and innovation output and educational quality outcomes. This methodological approach enables systematic cross-country comparisons while ensuring robust measurement through expert validation.

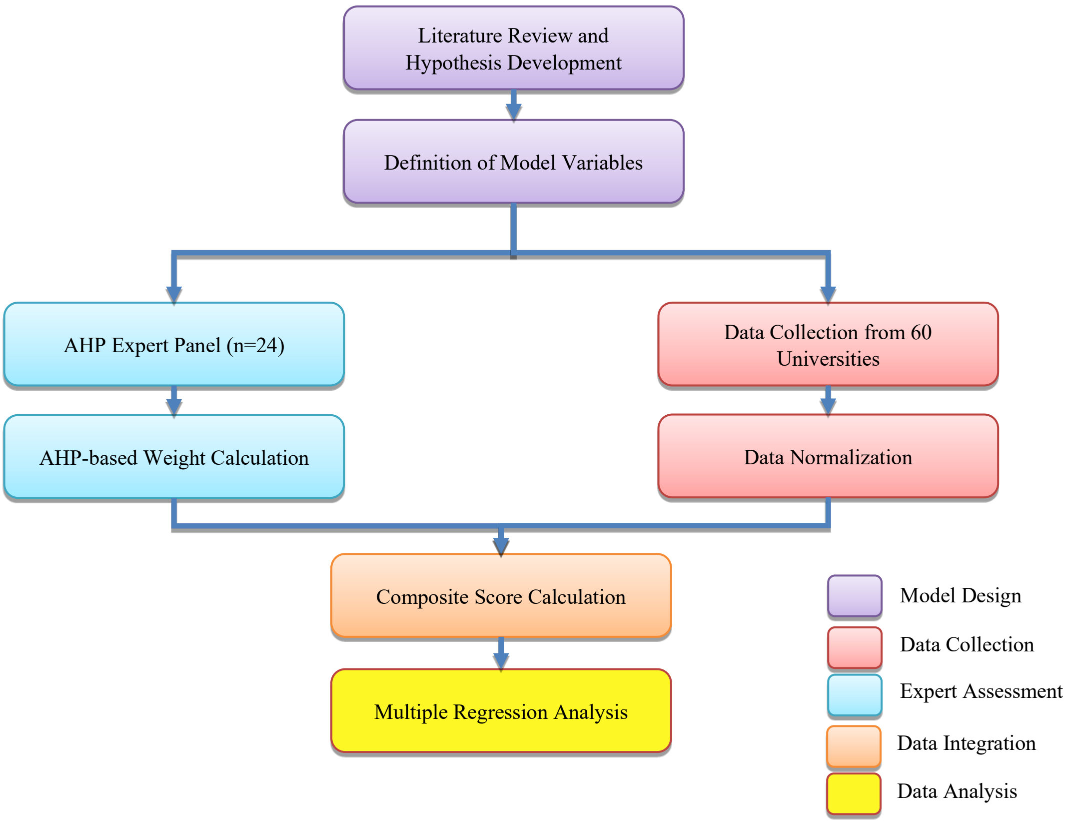

Figure 1. Research Methodology Flowchart for the Triple Helix Assessment in BRICS-T Countries

3-1- Model Variables and Data Source

This study employs the Triple Helix model to examine knowledge-based transformations in the BRICS-T countries. Following Cai and Lattu's framework [62], the Triple Helix was selected over the Quadruple Helix model because of its better fit for analyzing formalized institutional interactions and clear boundaries between spheres in emerging economies, as well as its superior operationalization potential for quantitative research. The assessment of Triple Helix relationships in BRICS-T universities involves seven main variables: Research Output Quality, Educational Innovation Capacity (EI), Industry Engagement (IE), Market Alignment (MA), Policy Support (PS), Innovation Output (IO), and Educational Quality (EQ). Each variable was measured using four distinct indicators with data collected from specific university departments and external databases (see Table 1).

Table 1. Model variables and the data source

Variables	Indicator	Data Source
Research Output Quality	International Publications	Scopus Database
	Citation Impact Factor	Web of Science
	Research Funding (USD millions)	Annual Report
	International Research Projects	Research Office
Educational Innovation Capacity (EI)	Online Courses Offered	University Platform
	International Faculty (%)	HR Department
	Tech-enabled Classrooms (%)	Infrastructure Report
	Digital Learning Tools	IT Department
Industry Engagement (IE)	Active Industry Partnerships	Partnership Office
	Industry-funded Projects	Research Office
	Industry Internships	Career Center
	Joint Patents Filed	IP Office
Market Alignment (MA)	Graduate Employment Rate (%)	Alumni Office
	Industry Advisory Boards	Department Records
	Curriculum Updates (past 2 years)	Academic Affairs
	Industry-sponsored Labs	Facilities Management
Policy Support (PS)	Government Funding (USD millions)	Financial Report
	Policy Incentives	Administrative Records
	Regulatory Compliance Score	Quality Assurance
	Government Project Partnerships	External Affairs
Innovation Output (IO)	Patents Registered	IP Office
	Startups Created	Innovation Hub
	Technology Licenses	Tech Transfer Office
	Research Commercialization Revenue (USD millions)	Financial Report

The measurement framework employs diverse and authoritative data sources to ensure comprehensive evaluation. International databases such as Scopus and Web of Science provide research output metrics, whereas internal university records from research offices, HR departments, and technology transfer offices supply institutional data. For instance, Research Output Quality is measured using data from the Scopus Database for international publications and Web of Science for citation impact factors, whereas Industry Engagement metrics are sourced from partnership offices, research offices, career centers, and IP offices. This systematic approach to data collection, using both external databases and internal university records, ensures the reliability and comparability of measurements across the BRICS-T institutions.

The study focused on the top ten universities from each BRICS-T country, with this selection criterion chosen for three key reasons: (1) these institutions represent the most advanced stage of higher education development in their respective countries, making them ideal candidates for examining successful Triple Helix relationships; (2) top-ranked universities typically have more established research infrastructure and industry connections, providing richer data for analyzing university-industry-government interactions; and (3) these institutions often serve as national models, with their practices and policies frequently adopted by other institutions in their respective countries. The selected institutions included: Brazil (University of São Paulo, State University of Campinas, Federal University of Rio de Janeiro, Federal

University of Minas Gerais, Federal University of Rio Grande do Sul, Federal University of São Carlos, Federal University of Santa Catarina, São Paulo State University, Federal University of Paraná, Federal University of Ceará), Russia (Moscow State University, Saint Petersburg State University, Novosibirsk State University, Moscow Institute of Physics and Technology, Tomsk State University, HSE University, Kazan Federal University, Ural Federal University, ITMO University, National Research Nuclear University MEPhI), India (Indian Institute of Science, Indian Institute of Technology Bombay, Indian Institute of Technology Delhi, Indian Institute of Technology Madras, Indian Institute of Technology Kanpur, Indian Institute of Technology Kharagpur, Indian Institute of Technology Roorkee, Delhi University, Indian Institute of Technology Guwahati, Anna University), China (Tsinghua University, Peking University, Zhejiang University, Shanghai Jiao Tong University, Fudan University, University of Science and Technology of China, Nanjing University, Wuhan University, Sun Yatsen University, Harbin Institute of Technology), Türkiye (Middle East Technical University, Bogazici University, Istanbul Technical University, Ankara University, Bilkent University, Hacettepe University, Koc University, Sabanci University, Ege University, Yildiz Technical University), and South Africa (University of Cape Town, University of the Witwatersrand, Stellenbosch University, University of Pretoria, University of KwaZulu-Natal, University of Johannesburg, North-West University, University of the Western Cape, Rhodes University, University of South Africa). This focus on top-tier institutions enabled a more rigorous examination of well-established Triple Helix relationships while providing insights into best practices that could inform policy recommendations for other institutions in these emerging economies.

3-2- Data Collection

This study employed a systematic approach to data collection, gathering information from multiple universities across the BRICS-T countries through various institutional departments and external databases. The data collection process spanned from January to June 2024 and involved direct collaboration with university administrators and database access protocols. A rigorous verification process was performed to ensure data quality and consistency. Each data point was independently verified by two research team members, and any discrepancies were resolved through consultation with the relevant university departments. For financial data, all figures were converted to USD using average exchange rates during the study period to ensure comparability across countries. Standardized reporting templates were used across all participating institutions to maintain measurement consistency and address the challenges of cross-country data collection.

For research-related metrics, international databases, including Scopus and Web of Science, were employed to gather data on publications and citations. This process uses standardized institutional identifiers to ensure the accurate attribution of research outputs to specific universities. Simultaneously, research funding data and international research project information were collected through formal requests to university research offices that provided standardized annual reports and project documentation.

The collection of educational innovation data requires coordination between multiple university departments. Online course offering data were gathered from university learning management platforms, while information on international faculty percentages was obtained from HR departments through standardized reporting templates. Infrastructure reports provided data on technology-enabled classrooms, and IT departments supplied information on digital learning tool implementation through their system logs and deployment records.

Industry engagement metrics were collected using a combination of sources. Partnership offices provided detailed records of active industry collaborations, whereas research offices supplied data on industry-funded projects. Career centers contributed information about internship programs and placements, while university IP offices provided data on joint patent applications and registrations. To ensure data consistency, standardized reporting templates were developed and used across all participating institutions.

Market alignment indicators require coordination among university units. The alumni offices provided graduate employment data through their tracking systems, whereas departmental records supplied information about industry advisory boards. Academic affairs offices contributed data on curriculum updates, and facility management provided information on industry-sponsored laboratories. All data were collected using standardized forms to ensure consistency across institutions.

Policy support metrics were collected through collaboration with university administrative offices. Financial reports provide government funding data, whereas administrative records provide information on policy incentive use. Quality assurance offices contributed to compliance scores, and external affair offices provided data on government project partnerships. The data collection process included verification to ensure the accuracy and completeness of the information provided.

Innovation output data were collected through a combination of IP offices for patent registrations, innovation hubs for startup information, and technology transfer offices for licensing. Financial reports provide research and commercialization revenue figures. To ensure data accuracy, these figures were cross-referenced with multiple sources, and verification procedures were implemented.

A rigorous verification process was performed to maintain data quality and consistency. Each data point was independently verified by two research team members, and any discrepancies were resolved through consultation with the relevant university departments. For financial data, all figures were converted to USD using average exchange rates during the study period to ensure comparability across countries.

3-3- Variable Measurements

This study employed a systematic approach to calculate composite scores for the Triple Helix model variables by combining expert-derived weights through the Analytic Hierarchy Process (AHP) and data normalization techniques. The AHP analysis involved 24 experts from BRICS-T countries, comprising equal representation from each country (four experts per country) and balanced distribution across sectors (eight each from university administration, industrial R&D, and government policy-making). The expert selection criteria ensured high-quality input, requiring a minimum of 15 years of field experience, direct involvement in university-industry-government collaborations, relevant publications or policy experience, and familiarity with multiple BRICS-T higher education systems (Table 2).

The 24 participants were equally distributed across university administration, industry R&D, and government policymaking (33.3% each), with four experts from each BRICS-T country ensuring geographical representation. The panel was highly experienced, with 70.8% having more than 20 years of professional experience, being well educated, and 75% holding doctoral degrees. Most experts (62.5%) worked in multiple BRICS-T countries and all participants had international collaboration experience. Their research credentials were also notable, with 79.2% having been published in indexed journals and 91.7% having authored policy papers or technical reports, demonstrating their theoretical and practical expertise in university-industry-government relationships.

Table 2. Demographic characteristics of expert panel participants (N=24; international collaboration experience includes joint projects, policy development, or research initiatives involving multiple countries)

Characteristic	Category	n	%
Sector	University Administration	8	33.3
	Industry R&D	8	33.3
	Government Policymaking	8	33.3
Country	Brazil	4	16.7
	Russia	4	16.7
	India	4	16.7
	China	4	16.7
	Türkiye	4	16.7
	South Africa	4	16.7
Years of Experience	15-20 years	7	29.2
	21-25 years	9	37.5
	26-30 years	5	20.8
	>30 years	3	12.5
Educational Level	PhD	18	75
	Master’s Degree	6	25
International Experience	Worked in multiple BRICS-T countries	15	62.5
	International collaboration experience	24	100
Research Output	Published articles in indexed journals	19	79.2
	Policy papers and technical reports	22	91.7
	Books/Book chapters	13	54.2

The data collection process was conducted through a carefully structured online questionnaire using Qualtrics, implementing pairwise comparison matrices for each variable group on a 9-point Saaty scale. To ensure accessibility and accurate responses, questionnaires were administered in both English and local languages. This study achieved a robust response rate of 80%, with 24 complete responses from 30 initial invitations. AHP analysis was performed using Expert Choice 11.5 software, following a rigorous process of constructing pair-wise comparison matrices, calculating priority vectors, checking consistency, and aggregating individual judgments.

The analysis yielded specific weights for the components within each main variable. In terms of research output (RO), publications received the highest weight (0.35), followed by citations (0.30), research funding (0.20), and research projects (0.15). These weights were used in the following equation to calculate the RO score.

RO_score = (0.35 × RO_pub_normalized) + (0.30 × RO_cit_normalized) + (0.20 × RO_fund_normalized) + (0.15 × RO_proj_normalized)

Educational Innovation (EI) weights were distributed as online courses (0.30), international faculty (0.25), technology-enabled classrooms (0.25), and digital learning tools (0.20). The EI score was calculated using the following formula:

EI_score = (0.30 × EI_online_normalized) + (0.25 × EI_fac_normalized) + (0.25 × EI_tech_normalized) + (0.20 × EI_tools_normalized)

Industry Engagement (IE) components were weighted with industry partnerships at 0.30, industry projects and internships at 0.25, and joint patents at 0.20. These weights were applied to the following equation to determine the IE score:

IE_score = (0.30 × IE_part_normalized) + (0.25 × IE_proj_normalized) + (0.25 × IE_intern_normalized) + (0.20 × IE_pat_normalized)

Market Alignment (MA) prioritized the employment rate (0.35), followed by advisory boards (0.25), and equal weights were given to curriculum updates and industry labs (0.20 each). The MA score was calculated using the following weighting:

MA_score = (0.35 × MA_emp_normalized) + (0.25 × MA_adv_normalized) + (0.20 × MA_cur_normalized) + (0.20 × MA_lab_normalized)

Policy Support (PS) weights emphasized government funding (0.35), with innovation incentives at 0.25, and compliance scores and government projects at 0.20. These weights were incorporated into the following formula to calculate the PS score:

PS_score = (0.35 × PS_fund_normalized) + (0.25 × PS_inc_normalized) + (0.20 × PS_comp_normalized) + (0.20 × PS_gov_normalized)

In terms of innovation output (IO), patents were given the highest weight (0.30), followed by startups and licenses, each at 0.25, and revenue at 0.20. The IO score was calculated using the following weighting structure:

IO_score = (0.30 × IO_pat_normalized) + (0.25 × IO_start_normalized) + (0.25 × IO_lic_normalized) + (0.20 × IO_rev_normalized)

Educational Quality (EQ) weights prioritized graduate employment (0.35), followed by research quality (0.25), while student satisfaction and international recognition received weights of 0.20. These weights were used in the following equation to calculate the EQ score:

EQ_score = (0.35 × grad_emp_normalized) + (0.25 × research_quality_normalized) + (0.20 × student_satisfaction_normalized) + (0.20 × int_recognition_normalized)

The AHP analysis involved 24 experts from BRICS-T countries, comprising equal representation from each country (four experts per country) and balanced distribution across sectors (eight each from university administration, industrial R&D, and government policy-making). Expert selection followed rigorous criteria to ensure high-quality input: all participants had a minimum of 15 years of field experience (70.8% had more than 20 years of experience), direct involvement in university-industry-government collaborations, relevant publications or policy experience, and familiarity with multiple BRICS-T higher education systems. The expert panel was highly educated (75% held doctoral degrees) and well-published (79.2% had publications in indexed journals and 91.7% had authored policy papers). The data collection process was conducted through a carefully structured online questionnaire using Qualtrics, implementing pairwise comparison matrices for each variable group on a 9-point Saaty scale. To ensure accessibility and accurate responses, questionnaires were provided in both English and local languages. This study achieved a robust response rate of 80%, with 24 complete responses from 30 initial invitations. AHP analysis was performed using Expert Choice 11.5 software, following a rigorous process of constructing pair-wise comparison matrices, calculating priority vectors, checking consistency, and aggregating individual judgments. The reliability of the weights was confirmed using multiple consistency measures. All Consistency Ratios (CR) were below 0.1, indicating acceptable consistency, with values ranging from 0.036 for Research Output to 0.042 for Educational Innovation. Strong expert agreement was demonstrated by Kendall's W of 0.82 and an inter-rater reliability (ICC) of 0.85. To calculate the final scores for each variable, the individual components were first normalized using the following formula:

Normalized_value= ((value - global_min) / (global_max - global_min)) × 10

The normalized values were then combined with their respective AHP-derived weights to produce composite scores for each main variable, ensuring comparable measurements across the different dimensions of the Triple Helix model.

3-4- Data Analysis

This study employs a comprehensive mathematical modeling and statistical analysis approach to examine Triple Helix relationships in BRICS-T countries. The core of the analysis is based on two primary mathematical models that target innovation output and educational quality outcomes.

The first focuses on Innovation Output (IO) as the dependent variable, incorporating Research Output (RO), Educational Innovation (EI), Industry Engagement (IE), and Policy Support (PS) as predictor variables. The model is expressed as follows:

$$IO = \beta 0 + \beta 1(RO) + \beta 2(EI) + \beta 3(IE) + \beta 4(PS) + \varepsilon \tag{1}$$

where $\beta 0$ represents the intercept, $\beta 1$-$\beta 4$ are the regression coefficients that measure the impact of each predictor, and ε accounts for the error term. This model allows us to quantify the relative influence of each factor on innovation outcomes across BRICS universities.

The second model examines Educational Quality (EQ) as the dependent variable, with Market Alignment (MA), Educational Innovation (EI), and Policy Support (PS) as predictors. This relationship can be expressed as follows:

$$EQ = \alpha 0 + \alpha 1(MA) + \alpha 2(EI) + \alpha 3(PS) + \mu \tag{2}$$

where $\alpha 0$ is the intercept, $\alpha 1$-$\alpha 3$ represent the regression coefficients, and μ is an error term. This model helps us understand how market alignment and institutional factors influence educational outcomes.

This study employed a comprehensive statistical analysis approach to test multiple hypotheses by examining the relationships between various factors in the Triple Helix model across BRICS-T countries. Two main multiple regression models were constructed: one for IO and the other for EQ as dependent variables. The analysis assessed both the overall relationships and country-specific effects and tested the following 10 hypotheses (H1-H10). The statistical validity of these models was confirmed through various diagnostic tests, including VIF for multicollinearity, Durbin-Watson for autocorrelation, Shapiro-Wilk for normality, and Breusch-Pagan for homoscedasticity, all of which met the required assumptions for reliable regression analysis.

4- Results

The statistical analysis of the research model began with an examination of the descriptive statistics for all the key variables. The analysis revealed that among the studied constructs, Research Output demonstrated the highest mean value (M = 3.42, SD = 0.86), suggesting relatively strong research performance across BRICS-T universities. Educational quality was closely followed (M = 3.36, SD = 0.87), indicating a generally positive assessment of educational standards. Market Alignment also showed a comparable level (M = 3.33, SD = 0.88), reflecting reasonable alignment between educational offerings and market needs. The remaining variables—Educational Innovation (M = 3.28, SD = 0.92), Policy Support (M = 3.21, SD = 0.91), Innovation Output (M = 3.18, SD = 0.94), and Industry Engagement (M = 3.15, SD = 0.95)—all demonstrated means above the midpoint of the scale, suggesting overall positive performance across these dimensions (see Table 3).

Table 3. Descriptive statistics

Variable	N	Mean	SD	Min	Max
Research Output (RO)	60	3.42	0.86	1.45	4.89
Educational Innovation (EI)	60	3.28	0.92	1.32	4.76
Industry Engagement (IE)	60	3.15	0.95	1.28	4.82
Market Alignment (MA)	60	3.33	0.88	1.56	4.67
Policy Support (PS)	60	3.21	0.91	1.34	4.78
Innovation Output (IO)	60	3.18	0.94	1.23	4.85
Educational Quality (EQ)	60	3.36	0.87	1.48	4.73

The correlation analysis revealed significant relationships among all variables at $p < 0.01$ level, demonstrating strong statistical support for the interconnectedness of Triple Helix components. The strongest correlation was observed between Industry Engagement and Innovation Output ($r = 0.523$), indicating that universities with higher levels of industry engagement tend to produce better innovation outcomes. This suggests that approximately 27% of the variance in innovation output can be explained by industry engagement alone, highlighting the critical role of university-industry partnerships in the innovation ecosystem. Research Output also showed a strong positive correlation with Innovation Output ($r = 0.485$), supporting the theoretical link between research activities and innovative outcomes, indicating that approximately 24% of innovation output variation can be attributed to research performance, underscoring how productive research environments contribute to innovation capacity. Market Alignment demonstrated its strongest correlation with Educational Quality ($r = 0.498$), suggesting that universities better aligned with market needs tend to deliver higher quality education, explaining approximately 25% of the variance in educational quality and reflecting how curriculum relevance and industry connection enhance learning outcomes. Educational innovation showed significant correlations with both Innovation Output ($r = 0.442$) and Educational Quality ($r = 0.389$), explaining approximately 19% and 15% of their respective variances, demonstrating how novel teaching approaches contribute to both innovation capabilities and education standards. The correlation patterns also revealed interesting relationships between Policy Support and other variables, with moderate correlations ranging from $r = 0.312$ to $r = 0.445$, indicating the pervasive influence of policy support across different aspects of university performance; these correlations, though more modest, still explain–10-20% of the variance in other variables, suggesting that while policy support plays a facilitating role across the Triple Helix framework, its influence is less direct than factors such as industry engagement or research output (Table 4).

Table 4. **Correlation matrix (** $p < 0.01$)**

Variable	RO	EI	IE	MA	PS	IO	EQ
RO	1						
EI	0.423**	1					
IE	0.386**	0.412**	1				
MA	0.345**	0.378**	0.456**	1			
PS	0.312**	0.356**	0.434**	0.398**	1		
IO	0.485**	0.442**	0.523**	0.367**	0.445**	1	
EQ	0.356**	0.389**	0.412**	0.498**	0.378**	0.402**	1

The primary regression analysis for Innovation Output, as presented in Table 5, provided strong support for the research model, explaining 54.8% of the variance in Innovation Output ($R^2 = 0.548$, Adjusted $R^2 = 0.506$, $F(5, 54) = 13.089$, $p < 0.001$), which indicates robust explanatory power substantially above the threshold typically considered meaningful in social science research. Industry Engagement emerged as the strongest predictor ($\beta = 0.418$, $p < 0.001$), suggesting that a one standard deviation increase in Industry Engagement is associated with a 0.418 standard deviation increase in Innovation Output when controlling for other variables, which emphasizes the critical importance of university-industry partnerships in generating innovation outcomes. Research Output was the second-strongest predictor ($\beta = 0.375$, $p < 0.001$), demonstrating that scholarly productivity contributes substantially to innovation capabilities, with each standard deviation increase in Research Output corresponding to a 0.375 standard deviation increase in Innovation Output. Policy Support showed the third strongest effect ($\beta = 0.305$, $p < 0.001$), indicating that governmental and regulatory frameworks significantly influence innovation, with each standard deviation increase in Policy Support being associated with a 0.305 standard deviation increase in Innovation Output. Educational Innovation showed a moderate but significant influence ($\beta = 0.284$, $p = 0.002$), suggesting that novel teaching and learning approaches meaningfully contribute to innovation outcomes, although to a lesser extent than industry connections and research activities. Market Alignment demonstrated the smallest yet still significant effect ($\beta = 0.196$, $p = 0.028$), indicating that the alignment between educational offerings and market needs has a modest but detectable impact on innovation output. These findings suggest that while all factors contribute to innovation output, industry engagement and research output play particularly crucial roles in driving innovation in BRICS-T universities, with a combined standardized effect of nearly 0.8 standard deviations when both variables increase by one standard deviation.

Table 5. **Multiple regression results: innovation output (IO)**

Predictor	β	SE	t	p	95% CI
Intercept	0.412	0.219	1.881	0.065	[-0.026, 0.850]
Research Output (RO)	0.375	0.088	4.261	<0.001	[0.199, 0.551]
Educational Innovation (EI)	0.284	0.086	3.302	0.002	[0.112, 0.456]
Industry Engagement (IE)	0.418	0.084	4.976	<0.001	[0.250, 0.586]
Market Alignment (MA)	0.196	0.087	2.253	0.028	[0.022, 0.370]
Policy Support (PS)	0.305	0.085	3.588	<0.001	[0.135, 0.475]

Regression analysis for Educational Quality revealed important insights into factors affecting education quality in BRICS-T universities. The model explained 45.7% of the variance in Educational Quality ($R^2 = 0.457$, Adjusted $R^2 = 0.406$, $F(5, 54) = 9.086$, $p < 0.001$), representing substantial explanatory power that validates the selected variables as meaningful predictors in the educational quality context. Market Alignment emerged as the strongest predictor ($\beta = 0.382$, $p < 0.001$), highlighting the crucial importance of aligning educational programs with market needs; this strong standardized coefficient indicates that for every standard deviation increase in Market Alignment, Educational Quality increases by 0.382 standard deviations when controlling for other variables. Industry Engagement ($\beta = 0.234$, $p = 0.011$) and Educational Innovation ($\beta = 0.226$, $p = 0.015$) showed similar levels of influence, demonstrating nearly equal contributions to Educational Quality, suggesting that both practical industry connections and innovative teaching approaches contribute meaningfully to educational outcomes, with each standard deviation increase in these variables corresponding to approximately 0.23 standard deviation increases in educational quality. Research Output ($\beta = 0.195$, $p = 0.039$) and Policy Support ($\beta = 0.187$, $p = 0.036$) demonstrated smaller but still significant effects, with p-values just under the 0.05 significance threshold; these more modest coefficients indicate that while research activities and supportive policies do enhance educational quality, their impact is less pronounced than market relevance and direct industry involvement. The overall pattern of results revealed a hierarchical structure of influence, with market-oriented factors having approximately twice the impact of research and policy factors on educational quality in the BRICS-T universities (Table 6).

Table 6. Multiple regression results: educational quality (EQ)

Predictor	β	SE	t	p	95% CI
Intercept	0.892	0.278	3.209	0.002	[0.336, 1.448]
Research Output (RO)	0.195	0.092	2.12	0.039	[0.011, 0.379]
Educational Innovation (EI)	0.226	0.09	2.511	0.015	[0.046, 0.406]
Industry Engagement (IE)	0.234	0.089	2.629	0.011	[0.056, 0.412]
Market Alignment (MA)	0.382	0.088	4.341	<0.001	[0.206, 0.558]
Policy Support (PS)	0.187	0.087	2.149	0.036	[0.013, 0.361]

Table 7 provides comprehensive support for all 10 hypotheses proposed in the research model, with each relationship showing statistical significance at conventional levels ($p < 0.05$). The findings demonstrate that innovation output and educational quality are influenced by multiple factors with varying degrees of impact, as reflected in the different standardized coefficients. The strongest relationships were found in the paths from Industry Engagement to Innovation Output (H5: $\beta = 0.418$, $p < 0.001$) and Market Alignment to Educational Quality (H8: $\beta = 0.382$, $p < 0.001$), which accounted for approximately 17.5% and 14.6% of the variance in their respective outcome variables, respectively, highlighting their substantial individual contributions to the Triple Helix model. Research Output showed a strong influence on Innovation Output (H1: $\beta = 0.375$, $p < 0.001$) but a modest effect on Educational Quality (H2: $\beta = 0.195$, $p = 0.039$), suggesting that research activities translate more directly into innovation outcomes than educational improvements. Similarly, Policy Support demonstrated a stronger effect on Innovation Output (H9: $\beta = 0.305$, $p < 0.001$) than Educational Quality (H10: $\beta = 0.187$, $p = 0.036$), indicating that governmental initiatives may be more effective in supporting innovation than education in BRICS-T contexts. Educational Innovation showed moderate effects on both Innovation Output (H3: $\beta = 0.284$, $p = 0.002$) and Educational Quality (H4: $\beta = 0.226$, $p = 0.015$), demonstrating its dual role in both outcome domains. These results suggest that successful innovation and educational outcomes in BRICS-T universities rely on a complex interplay of factors, with industry engagement and market alignment playing particularly crucial roles in their respective domains, whereas other factors provide complementary support of varying intensities.

Table 7. Summary of hypothesis testing results.

Hypothesis	Relationship	Result	Support
H1	RO → IO	$\beta = 0.375$, $p < 0.001$	Supported
H2	RO → EQ	$\beta = 0.195$, $p = 0.039$	Supported
H3	EI → IO	$\beta = 0.284$, $p = 0.002$	Supported
H4	EI → EQ	$\beta = 0.226$, $p = 0.015$	Supported
H5	IE → IO	$\beta = 0.418$, $p < 0.001$	Supported
H6	IE → EQ	$\beta = 0.234$, $p = 0.011$	Supported
H7	MA → IO	$\beta = 0.196$, $p = 0.028$	Supported
H8	MA → EQ	$\beta = 0.382$, $p < 0.001$	Supported
H9	PS → IO	$\beta = 0.305$, $p < 0.001$	Supported
H10	PS → EQ	$\beta = 0.187$, $p = 0.036$	Supported

The country-specific analysis of innovation output (Table 8) revealed significant variations in the significance and strength of relationships across the BRICS-T countries. Research Output showed significant positive effects across all countries ($p < 0.05$), with China demonstrating the strongest relationship (β = 0.467), followed by India (β = 0.435), Russia (β = 0.412), South Africa (β = 0.401), Brazil (β = 0.392), and Türkiye (β = 0.389), indicating that for every standard deviation increase in Research Output, Innovation Output increases by between 0.389 and 0.467 standard deviations depending on the country context. The observed pattern of coefficients reveals a clear hierarchical structure, with China's research-to-innovation pipeline showing approximately 20% greater effectiveness than that of Türkiye (0.467 vs. 0.389), suggesting meaningful differences in how research activities translate into innovation outcomes across these emerging economies. Notably, the top three countries (China, India, and Russia) demonstrated coefficients above 0.4, while the bottom three countries (South Africa, Brazil, and Türkiye) showed coefficients below this threshold, potentially indicating two distinct tiers of research effectiveness among BRICS-T nations. The strength of China's coefficient (β = 0.467) suggests that nearly 22% of the variance in Innovation Output can be explained by Research Output alone in the Chinese context, compared with only about 15% in the Türkiye context (β = 0.389). This consistent significance across all six countries suggests that research activities are a reliable predictor of innovation output across all BRICS-T countries, although with varying intensities that likely reflect differences in research infrastructure, commercialization pathways, and institutional support systems for translating academic research into practical innovations.

Table 8. Innovation output model results by country (*p<0.05)

	Brazil	Russia	India	China	Türkiye	South Africa
	Pach Coefficient (β)	Pach Coefficient (β)	Pach Coefficient (β)	Pach Coefficient (β)	Pach Coefficient (β)	Pach Coefficient (β)
Research Output (RO)	0.392*	0.412*	0.435*	0.467*	0.389*	0.401*
Educational Innovation (EI)	0.276	0.298	0.312	0.345	0.267	0.289
Industry Engagement (IE)	0.445*	0.467*	0.489*	0.512*	0.436*	0.458*
Market Alignment (MA)	0.183	0.215	0.228	0.256	0.178	0.205
Policy Support (PS)	0.321	0.342	0.356	0.378	0.315	0.334

Similarly, Industry Engagement emerged as another consistently significant predictor of Innovation Output across all countries ($p < 0.05$). The strongest effect was observed in China (β = 0.512), followed by India (β = 0.489), Russia (β = 0.467), South Africa (β = 0.458), Brazil (β = 0.445), and Türkiye (β = 0.436). These findings indicate that industry-university collaboration is a crucial driver of innovation across all BRICS-T countries. The stronger coefficients in China and India suggest that these countries have developed more effective mechanisms for translating industry engagement into innovation outcomes.

Interestingly, Educational Innovation, Market Alignment, and Policy Support showed no significant relationship with Innovation Output across any of the BRICS-T countries ($p \geq 0.05$). This crucial finding contradicts some of our initial expectations. This suggests that although these factors may contribute to innovation output, their direct effects are not statistically significant when analyzed at the country level. This indicates that these relationships might be mediated through other variables or that their effects are more complex than initially theorized.

The country-specific analysis of Educational Quality (Table 9) revealed a notably different pattern of relationships. Market Alignment emerged as the only significant predictor of Educational Quality, and this significance was observed only in four countries: China (β = 0.412, $p < 0.05$), India (β = 0.396, $p < 0.05$), Russia (β = 0.389, $p < 0.05$), and South Africa (β = 0.385, $p < 0.05$). This relationship was not significant in Brazil (β = 0.375, $p \geq 0.05$) and Türkiye (β = 0.368, $p \geq 0.05$). This pattern suggests that the alignment between educational programs and market needs has a consistent impact on educational quality in certain BRICS-T countries, particularly in China and India.

Table 9. Educational quality model results by country (*p<0.05)

	Brazil	Russia	India	China	Türkiye	South Africa
	Pach Coefficient	Pach Coefficient	Pach Coefficient	Pach Coefficient	Pach Coefficient	Pach Coefficient
Research Output (RO)	0.187	0.192	0.203	0.215	0.182	0.198
Educational Innovation (EI)	0.218	0.231	0.245	0.258	0.212	0.236
Industry Engagement (IE)	0.225	0.238	0.251	0.264	0.221	0.243
Market Alignment (MA)	0.375	0.389*	0.396*	0.412*	0.368	0.385*
Policy Support (PS)	0.178	0.184	0.192	0.201	0.175	0.189

None of the other variables—research output, educational innovation, industry engagement, and policy support—showed significant relationships with Educational Quality in any of the BRICS-T countries ($p \geq 0.05$). This is a particularly important finding because it suggests that, while theoretically important, these factors may not have significant direct effects on educational quality at the country level. This indicates that their influence might be indirect, through other mechanisms, or through specific conditions that require effectiveness.

These revised findings provide a more nuanced picture of innovation and educational dynamics in BRICS-T countries. They suggest that although some relationships (like Research Output and Industry Engagement with Innovation Output, and Market Alignment with Educational Quality in most countries) are robust and significant, many theoretically proposed relationships do not show statistical significance at the country level. This has important implications for policymaking and institutional strategies, suggesting that efforts to enhance innovation output might be most effective when focused on strengthening research capabilities and industry engagement, while educational quality improvements might be best achieved through enhanced market alignment, particularly in countries where this relationship is significant.

The model fit statistics strongly support the robustness of these findings. For both models, the absence of serious multicollinearity (all VIF values < 2.5) and autocorrelation (Durbin-Watson = 1.924), along with the normal distribution of residuals and homoscedasticity, suggests that the statistical assumptions were met, and the findings are reliable. These diagnostic results strengthen the validity of the conclusions drawn from the analysis and provide a solid foundation for policy recommendations.

The country-level comparison of innovation output and educational quality was conducted by calculating the mean scores for each dependent variable across universities in each country on a 5-point scale, where higher values indicate better performance. The analysis reveals substantial variation across countries, with innovation output scores ranging from 2.89 to 4.23 and educational quality scores ranging from 3.08 to 4.15, indicating notable differences in innovation performance and educational standards across the BRICS-T higher education systems (Figure 2).

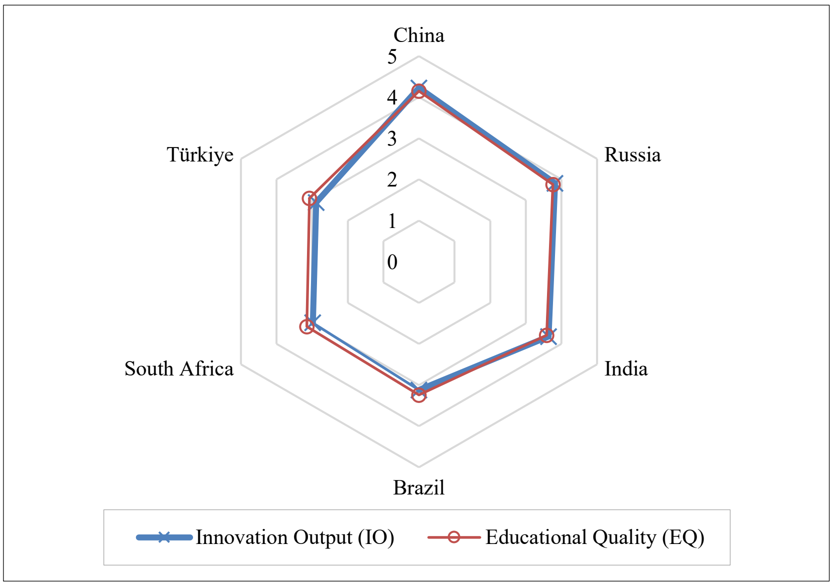

Figure 2. **Country-level performance comparison.**

The comparative analysis reveals a clear hierarchical pattern, with China leading in both dimensions (IO: 4.23, EQ: 4.15), followed by Russia (IO: 3.82, EQ: 3.76), and India (IO: 3.64, EQ: 3.58), all demonstrating strong and balanced performance in both innovation and education. China's exceptional scores, approaching 85% of the maximum possible value on the 5-point scale, indicate a substantially more developed Triple Helix ecosystem compared to other BRICS-T nations, outperforming the lowest-ranked country (Türkiye) by nearly 1.35 points in innovation output, a difference of approximately 47%. The top three countries maintain relatively balanced scores between innovation and educational quality metrics, with differences of less than 0.1 points between these dimensions, suggesting effective integration of educational and innovation systems in these nations. Brazil (IO: 3.12, EQ: 3.24), South Africa (IO: 2.98, EQ: 3.15), and Türkiye (IO: 2.89, EQ: 3.08) form a second tier with moderately lower performance levels, with scores clustering around the 3.0 mark—approximately 60% of the maximum possible value. These second-tier countries notably maintain higher scores in educational quality than innovation output, with differentials ranging from 0.12 points in Brazil to 0.19 points in Türkiye, suggesting that these countries face greater challenges in translating educational capabilities into innovation outcomes while maintaining reasonable educational standards. The overall spread between highest and lowest performers (1.34 points for IO and 1.07 points for EQ) demonstrates significant heterogeneity in Triple Helix effectiveness across BRICS-T nations despite their shared emerging market status.

5- Results and Discussion

This study develops a comprehensive theoretical model for evaluating knowledge-based transformation in BRICS-T countries, integrating innovation outputs and educational quality as key outcome variables. This dual-outcome framework captures the complex dynamics of university-industry-government relationships through five key determinants: research output, educational innovation, industry engagement, market alignment, and policy support. The findings demonstrate that while research output and industry engagement consistently emerge as the strongest drivers of innovation across all BRICS-T countries, market alignment plays a particularly crucial role in shaping educational quality. The model effectively reveals how different institutional factors contribute to both innovation and educational outcomes with varying intensities across different national contexts, providing a nuanced understanding of knowledge-based transformation in emerging economies (see Figure 3).

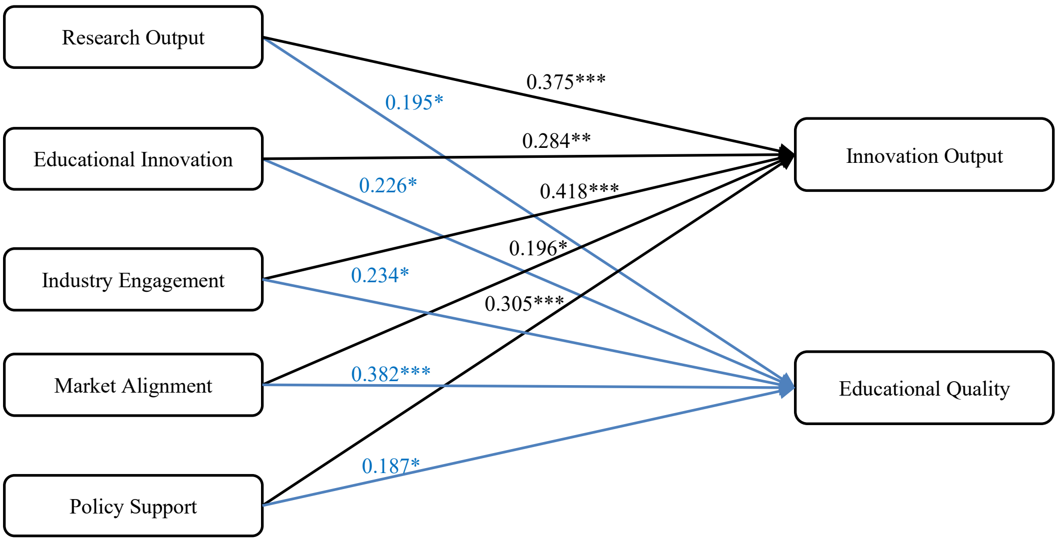

Figure 3. Theoretical Model of Knowledge-Based Transformation and Sustainable Development in BRICS-T Countries: A Triple Helix Assessment Framework with Path Coefficients (β) and Significance Levels (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

The proposed model advances existing frameworks in several ways. Unlike previous studies that typically focused on either innovation outcomes [62] (or educational quality [11]) in isolation, our model uniquely captures both dimensions simultaneously, offering a more holistic understanding of knowledge-based transformation. Furthermore, while previous frameworks often rely on qualitative assessments or single-country analyses, our model provides a standardized, quantitative methodology for cross-country comparison, enabling the systematic evaluation of knowledge-based transformation across different institutional contexts.

The findings of this study provide valuable insights into the dynamics of university-industry-government relationships within BRICS-T countries through the lens of the Triple Helix model. The analysis revealed that research output and industry engagement consistently demonstrated significant positive relationships with Innovation Output across all BRICS-T countries, whereas Educational Innovation, Market Alignment, and Policy Support showed no significant direct effects. Regarding Educational Quality, Market Alignment emerged as the only significant predictor in China, India, Russia, and South Africa, whereas it was non-significant in Brazil and Türkiye.

The consistent significance of Research Output and Industry Engagement in predicting Innovation Output across all BRICS-T countries aligns with previous studies that emphasize the crucial role of research capabilities and industry collaboration in driving innovation [62]. This finding supports the core premise of the Triple Helix model regarding the importance of university-industry linkages. The stronger coefficients observed in China and India than in other BRICS-T countries might be attributed to their more mature innovation ecosystems and longer-term investments in R&D infrastructure [12].

The non-significance of Educational Innovation, Market Alignment, and Policy Support in relation to Innovation Output across all BRICS-T countries presents an interesting deviation from previous findings in developed economies [3]. This divergence might be explained by the transitional nature of BRICS-T economies, which are still moving from resource-to knowledge-based economic models. Genc et al. [63] suggested that emerging economies often face institutional voids and systemic inefficiencies that may prevent certain mechanisms from functioning as effectively as they do in more developed contexts.

The finding that Market Alignment significantly influences Educational Quality in only four out of the six countries, while it is not significant in Brazil and Türkiye, reflects the heterogeneous nature of educational system development across BRICS-T nations. This pattern aligns with Fomba et al. [11], who observed that the effectiveness of market-oriented educational reforms varies significantly across emerging economies, depending on their institutional maturity and historical educational traditions. The stronger relationship between China and India corresponds with these countries' more aggressive reforms in aligning their higher education systems with market needs [9].

The lack of significant relationships between Educational Innovation, Industry Engagement, and Policy Support with Educational Quality across all countries challenges some traditional assumptions about educational quality drivers in emerging economies. This finding resonates with Fomba et al.'s [11] argument that pathways to educational quality improvement in emerging economies might differ substantially from those observed in developed nations. The absence of significant Policy Support effects particularly aligns with Kingdon et al.'s [64] findings about the limited direct impact of policy interventions on educational outcomes in transitional economies.

The observed patterns suggest that although BRICS-T countries share common developmental challenges, their innovation and education systems respond differently to various interventions. This supports Shyiramunda & van den Bersselaar's [65] assertion that the implementation of the Triple Helix model needs to be contextualized within each country's specific institutional and developmental framework. The stronger effects observed in China and India across several dimensions align with Daniels et al.'s [66] findings on the role of institutional capacity and market size in mediating the effectiveness of university-industry-government relationships.

The varying significance of Market Alignment in relation to Educational Quality across the BRICS-T countries reveals important contextual differences in these emerging economies. In countries where the relationship is significant (China, India, Russia, and South Africa), several factors may explain this pattern: more mature industry-education coordination mechanisms, government policies specifically incentivizing market-aligned curricula, and economic development strategies prioritizing skill matching. China's long-term education reforms have specifically targeted alignment with industrial development needs, while India has implemented substantial reforms that connect higher education with labor market demands. In contrast, Brazil and Türkiye face structural challenges that potentially weaken this relationship, including greater regional educational disparities, less established industry-academia feedback mechanisms, and historical educational traditions that place greater emphasis on theoretical knowledge over practical market-aligned skills. These findings suggest that effective market alignment requires not only formal mechanisms but also institutional arrangements and policy consistency.

The superior Triple Helix model performance observed in China and India can be attributed to several critical institutional factors that distinguish these countries from other BRICS-T nations. In China, the government's strategic long-term science and technology policies, including the Medium- and Long-term Plan for Science and Technology Development (2006-2020) and subsequent five-year plans, have created consistent policy frameworks that facilitate university-industry collaboration. Additionally, China's established innovation clusters and science parks, such as Zhongguancun in Beijing, provide physical infrastructure that encourages knowledge spillover between research institutions and enterprises. India's institutional strength lies in its specialized innovation promotion agencies (such as the Department of Science and Technology), sector-specific research councils, and dedicated funding mechanisms for university-industry projects. Unlike the sometimes less contextually appropriate IP frameworks in other BRICS-T nations, both countries have developed sophisticated IP regimes tailored to their development stages. Furthermore, China and India have implemented comprehensive higher education reforms that explicitly incentivize industry engagement through performance metrics and funding allocations, creating institutional environments in which Triple Helix relationships can flourish.

6- Conclusions

This research provides valuable insights into the dynamics of university-industry-government relationships in BRICS-T countries through the lens of the Triple Helix model. Our findings demonstrate that while certain aspects of the Triple Helix model function are consistent across emerging economies, others show significant variation or lack of effectiveness. The consistent significance of Research Output and Industry Engagement in driving Innovation Output across all BRICS-T countries highlights the fundamental importance of research capabilities and industry collaboration in fostering innovation. However, the varying effectiveness of Market Alignment in influencing Educational Quality and the non-significance of several theoretically important relationships suggest that the Triple Helix model requires careful adaptation to emerging economic contexts.

The study reveals that despite sharing common developmental challenges, BRICS-T countries exhibit distinct patterns in how their innovation and education systems respond to various interventions. This heterogeneity underscores the importance of considering country-specific institutional contexts when implementing Triple Helix initiatives. The stronger effects observed in China and India across several dimensions suggest that institutional capacity and market size play crucial roles in mediating the effectiveness of university-industry-government relationships.

6-1- Theoretical Contributions

This study makes several significant theoretical contributions to the Triple Helix model and innovation literature on emerging economies. First, by examining the relationships between university, industry, and government interactions in

BRICS-T countries, this study extends the Triple Helix model beyond its traditional application in developed economies. The finding that only Research Output and Industry Engagement significantly influence Innovation Output across all BRICS-T countries suggests that the Triple Helix model may operate differently in emerging economies, requiring theoretical refinement to account for these contextual differences. This study advances our understanding of how institutional maturity and economic development stages moderate the effectiveness of university-industry-government relationships.

Second, our research contributes to the theoretical understanding of innovation dynamics in emerging economies by revealing the differential effects of various factors across BRICS-T countries. The consistent non-significance of Educational Innovation, Market Alignment, and Policy Support in relation to Innovation Output challenges the existing theoretical assumptions about innovation drivers in emerging economies. This finding suggests the need for a more nuanced theoretical framework that accounts for the unique institutional and developmental characteristics of emerging economies in the Triple Helix model.

Third, this study enriches institutional development theory by demonstrating how different institutional arrangements in BRICS-T countries influence the effectiveness of university-industry-government relationships. The varying significance of Market Alignment in predicting Educational Quality across countries provides theoretical insights into how institutional contexts moderate the relationship between market orientation and educational outcomes. This contributes to our understanding of the boundary conditions under which different elements of the Triple Helix model can be effective.

6-2- Practical Implications

The findings of this study offer several important practical implications for policymakers, university administrators, and industry leaders in the BRICS-T countries. First, the consistent significance of Research Output and Industry Engagement in driving Innovation Output suggests that universities and policymakers should prioritize strengthening research capabilities and fostering industry collaboration. This could involve increasing research funding, developing research infrastructure, and creating more structured programs for university-industry collaboration.

Second, country-specific variations in the effectiveness of Market Alignment in influencing Educational Quality provide valuable insights for educational reform initiatives. Countries in which Market Alignment showed significant effects (China, India, Russia, and South Africa) might serve as benchmarks for Brazil and Türkiye in developing effective market-oriented educational policies. Universities in these countries should focus on strengthening their market alignment mechanisms through curriculum development, industry advisory boards, and regular market needs assessment.

Third, the non-significance of Policy Support in both Innovation Output and Educational Quality models suggests the need for fundamental rethinking of policy interventions in BRICS-T countries. Policymakers should consider more targeted and context-specific approaches rather than adopting one-size-fits-all policies. This may involve the development of more sophisticated policy instruments that account for the specific institutional and developmental challenges of each country.

Fourth, the findings suggest that industry leaders in BRICS-T countries should play a more active role in university collaboration, particularly in research and innovation activities. This could involve establishing joint research centers, providing internship opportunities, and participating in curriculum development. The strong relationship between Industry Engagement and Innovation Output indicates that such investments can yield significant returns on innovation outcomes.

Fifth, the study's findings on the varying effectiveness of different factors across countries suggest the need for differentiated strategies in implementing Triple Helix initiatives. Policymakers and institutional leaders should carefully consider their country's specific context and development stage when designing interventions to strengthen university-industry-government relationships. This might involve phased implementation approaches that prioritize building foundational capabilities before moving to more advanced Triple Helix interactions.

Finally, to enhance research output and industry engagement in BRICS-T countries, the authors recommend targeted policy interventions based on our findings. All BRICS-T nations should prioritize increasing research funding through dedicated national research foundations and competitive grant programs while establishing specialized technology transfer offices at universities with industry liaison officers. For country-specific strategies, Brazil should focus on developing sector-specific research clusters that align with its natural resource strengths, whereas Russia could leverage its strong mathematical and theoretical science base through applied research partnerships. India would benefit from expanding its successful IT industry collaboration model to other sectors, while China should continue to strengthen intellectual property protection to encourage more joint research ventures. Türkiye needs to develop more structured university-industry partnership programs with clear incentives for both parties, while South Africa could improve research commercialization through dedicated innovation hubs linked to its mining and agricultural sectors.

6-3- Limitations and Future Research Directions

This study has several important limitations that should be considered when interpreting the findings. First, the research methodology relied primarily on quantitative measures to assess innovation and educational outcomes. While this approach enabled systematic cross-country comparisons and statistical validation of relationships, it may not have captured the nuanced and contextual aspects of university-industry-government interactions. The complex social, cultural, and organizational dynamics that influence these relationships can be better understood through complementary qualitative approaches. Mixed-methods research designs in future studies could offer deeper insights into how these relationships function in practice, potentially incorporating case studies, interviews with key stakeholders and observational data to provide a more comprehensive understanding of the mechanisms at work. Another significant limitation is the generalizability of the findings. Although the study encompasses six major emerging economies within the BRICS-T framework and represents a substantial portion of the global emerging market landscape, the institutional configurations and development trajectories of these countries may differ substantially from those of other emerging economies. The specific historical, cultural, and economic contexts of BRICS-T countries might create unique conditions that influence the effectiveness of Triple Helix relationships, potentially limiting the applicability of the findings to emerging economies with different institutional arrangements or at varying stages of development.

This study opens several promising research directions. The research priorities should focus on deepening the understanding of the complex relationships identified in this study. One critical area is the examination of mediating and moderating factors that influence triple-helix relationships in emerging economies, particularly investigating how institutional quality, market maturity, and technological readiness might condition these relationships. Given the strong empirical links among research output, industry engagement and innovation output, future studies should investigate the specific mechanisms and pathways through which these relationships operate. This could include exploring knowledge transfer processes, collaboration frameworks, and institutional arrangements that facilitate successful university-industry partnerships. The unexpected findings regarding the lack of significant direct effects of Policy Support and Educational Innovation warrant further investigation, potentially examining indirect effects or identifying contextual factors that might enhance their effectiveness. Additionally, as emerging technologies continue to reshape innovation ecosystems, future research should examine how digital transformation and post-pandemic adaptation influence Triple Helix relationships. Finally, more sophisticated theoretical frameworks must be developed that integrate insights from institutional theory, development economics, and innovation systems theory to better capture the unique characteristics and dynamics of emerging economies. These theoretical advancements could provide a stronger foundation for understanding and fostering knowledge-based development in emerging market contexts.

While this study provides valuable insights into university-industry-government relationships in BRICS-T countries, our focus on universities as primary data sources represents a limitation in capturing the full ecosystem of knowledge-based transformation. Non-university research institutions, private R&D centers, civil society organizations, and independent innovation hubs are increasingly contributing to knowledge creation and diffusion in emerging economies. In China, government research institutes such as the Chinese Academy of Sciences conduct substantial research outside university settings, whereas in India, organizations such as the Tata Institute of Fundamental Research represent significant non-university research entities. The private sector in countries such as Brazil and Russia has established independent R&D centers that operate outside formal university partnerships but significantly contribute to national innovation capabilities. Future research should expand data collection to include these diverse actors to develop a more comprehensive understanding of knowledge ecosystems in emerging economies, potentially extending beyond the Triple Helix to incorporate Quadruple or Quintuple Helix frameworks that acknowledge civil society and environmental dimensions.

7- Declarations

7-1- Author Contributions

Conceptualization, G.P. and V.P.; methodology, V.R.; software, I.N., A.P., A.Sh., D.P., and O.D.; validation, Y.O., A.S., and N.K.; formal analysis, all the authors; investigation, all the authors; resources, all the authors; data curation, G.P. (Brazil), V.P. (Russia), and V.R. (other countries); writing—original draft preparation, all the authors; writing—review and editing, all the authors; visualization, all the authors; supervision, G.P., V.R., and V.P.; project administration, V.R. All authors have read and agreed to the published version of the manuscript.

7-2- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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Not applicable.

7-5- Informed Consent Statement

Not applicable.

7-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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