“Evaluating the nexus of funding and scientific output in Kazakhstan”

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EVALUATING THE NEXUS OF FUNDING AND SCIENTIFIC OUTPUT IN KAZAKHSTAN

Abstract

This study examines the dynamics and effectiveness of investments in Kazakhstan's research and development (R&D). The primary aim is to assess the efficiency of scientific research activities in Kazakhstan by analyzing the relationship between R&D investments and scientific outputs across different periods. As a methodological approach, Data Envelopment Analysis (DEA) calculates efficiency indicators by transforming multiple inputs into outputs. Descriptive analysis comprehensively explains trends and patterns in R&D funding, scientific publications, and patent registrations. The results reveal a substantial increase in R&D expenditure. Despite this, the share of domestic R&D expenditures from the gross domestic product (GDP) declined from 0.25% to 0.12%. The analysis also uncovered a significant surge in scientific publications, with Scopus publications increasing from 1,799 to 28,280 and Web of Science publications rising from 1,468 to 20,532 across the study period. However, a contrasting trend was observed in patent registrations, which decreased from 6,968 to 2,612, indicating potential inefficiencies in translating research into innovations. The study concludes that while Kazakhstan has demonstrated notable progress in enhancing research output, the decline in patent registrations relative to the increase in R&D investments underscores the need for strategic initiatives. These should strengthen industry-academia collaboration, enhance innovation infrastructure, and balance incentives for publications and patents, ensuring that R&D investments translate into tangible innovations and contribute effectively to the nation's socio-economic development.

Keywords research evaluation, funding models, research policy, indicators, scientific publications, Scopus, R&D investment

JEL Classification O32, I23, H52

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INTRODUCTION

The effectiveness of investments in research and development (R&D) is a critical factor that influences a country's scientific advancement, technological progress, and economic growth. Understanding the dynamics of R&D investments and their correlation with scientific outcomes is becoming increasingly pertinent, particularly for emerging economies aspiring to establish themselves as key players on the international stage.

This is especially relevant for Kazakhstan, a country committed to fostering a robust and innovative research environment as part of its broader developmental strategy. Over the last two decades, Kazakhstan's scientific sector has witnessed significant transformations reflecting global R&D trends and the country's unique socio-economic dynamics. The reform of Kazakhstan's scientific landscape has been a strategic measure, aligning the nation's research infrastructure and policy with models used by leading countries. The introduction of transparent and standardized criteria across various aspects of scientific activity, including the composition of the National Scientific

Council, funding competitions, recognition of scientific achievements, and scholarships, marks a significant leap towards a more open and optimized research environment. Consequently, debates continue in Kazakhstan, as in many countries worldwide, regarding the effectiveness of R&D investments and their tangible impact on scientific productivity.

The scientific problem addressed in this study involves a comprehensive analysis and understanding of the impact of increased research funding on quantity of scientific output. This will contribute to a broader understanding of how financial investments in science shape the research landscape and what this implies for the country's position in the global scientific community.

1. LITERATURE REVIEW

Evaluating research effectiveness is crucial for understanding and enhancing their contribution to scientific progress and societal development. For developing countries amid reforms and transformations in higher education and science, creating reliable and multidimensional assessment indicators is essential for meeting international standards and promoting the strategic development of national academic and research institutions.

Chen et al. (2023) provide a foundational perspective by introducing the Malmquist index as a tool for measuring the performance of university research, particularly in the context of sustainable competitive advantage. Their approach, which incorporates a range of factors, including funding and research outcomes, sets a precedent for a comprehensive assessment model that can be adapted to the context of Kazakhstan's higher education system.

Another study suggests the use of Data Envelopment Analysis to evaluate the efficiency of input and output data of universities in a specific economic zone (Wang et al., 2023). Focusing on the relationship between research investments and academic outcomes, their findings highlight the importance of efficient resource allocation, a crucial aspect for universities in pursuing optimal productivity.

Shi et al. (2022) explore the divide between fundamental and applied research in assessing scientific efficiency. Zhao and Lu (2019) provide a more focused lens, investigating the scientific efficiency of student universities at the provincial level. Their work underscores the presence of individual variations in research performance, suggesting the need for tailored strategies – a lesson that could guide the development of higher education policy in Kazakhstan (Zhao & Lu, 2019).

Researchers also propose an approach based on the expanded use of Data Envelopment Analysis to measure the joint efficiency of teaching and research (Kuah & Wong, 2011). This dual assessment is particularly relevant as it aligns with the multifaceted mission of universities, suggesting that institutions should adopt a holistic view in their efficiency assessments.

Chao and Chen (2023), which evaluate the efficiency of university faculties through DEA, offer a profound methodological approach. Their focus on departmental productivity provides a micro-level perspective that can inform macro-level evaluations of the efficiency of higher education research (Chao & Chen, 2023).

Measuring research productivity remains a challenging task, especially in the context of a rapidly evolving scientific landscape. Assessing the cost-effectiveness of research plays a key role, yet internal complexities, such as determining the impact of investments, complicate this process (Riley et al., 2017). Increased funding opportunities have created a competitive environment for researchers seeking grants, but this also introduces difficulties in assessment due to the diversity of funding channels and programs, each with its own criteria and evaluation processes (Ebadi & Schiffauerova, 2016; Butler, 2003). The complexity is further amplified by international diversified collaborations, within which determining the contribution and impact of individual participants becomes increasingly complex (Wagner & Leydesdorff, 2005). These circumstances necessitate the development of advanced assessment methods that account for the interaction and interdependence in global scientific cooperation.

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Developed countries have already implemented changes in research management and funding schemes that include efficiency-based financial models, outcome-oriented evaluations, and strategic planning, which can serve as an essential example for developing economies (Hicks, 2012).

Traditional research productivity indicators, such as publications and citations, do not reflect the full spectrum of research activities, as they do not cover elements such as data exchange and societal impact (Bohdanov et al., 2023; Petrushenko et al., 2023; Wilsdon, 2016). The time lag between research investments and their outcomes, which can span years, complicates the accurate impact assessment (Martin & Irvine, 1983). Interdisciplinary research that transcends individual disciplines also poses challenges for evaluation, as traditional approaches favor mono-disciplinary study and do not account for interdisciplinary contributions (Bornmann & Marx, 2014). Developing new assessment methods that consider these aspects is essential for fully recognizing research contributions.

Evaluating the effectiveness and productivity of research is a complex task that extends beyond individual researchers or institutions, affecting the entire scientific ecosystem (Baccini et al., 2019; Edwards & Roy, 2017; Baas et al., 2020). Assessing the contributions of collaborative research networks and the efficiency of investments from funding agencies and policymakers requires a comprehensive approach (Mâsse et al., 2008; Dziallas & Blind, 2019).

The importance of factors such as a country's economic development, the state of reforms in science, the specifics of national policies, science funding and its share of GDP, as well as geopolitical circumstances and socio-economic crises, influences the entire spectrum of assessment, from the individual work of scientists to a country's global scientific reputation (Lopatina et al., 2023; Suchikova et al., 2023; Zhu, 2020; Liang et al., 2022).

Thus, it becomes clear that the significance of scientific achievements lies not only in their immediate results but also in the profound impact of scientific activity on the development of society and the economy, highlighting the need to ensure a harmonious relationship between a country's GDP and adequate science funding for its sustainable progress (Compagnucci & Spigarelli, 2020). However, there is not always a linear relationship between science funding and the quantity of scientific output; often, significant factors such as the migration of scientific personnel (Polishchuk et al., 2023), researchers' mental health (Tsybuliak et al., 2023), their motivation (Altenmüller et al., 2021), and the ability to realize scientific potential in rapidly changing conditions play a significant role. Developing such a methodology should be essential to improving scientific efficiency and enhancing scientific research's role in nations' socio-economic development.

In summary, the literature review highlights the complexities of assessing research effectiveness in higher education, particularly in the context of developing countries. It underscores the limitations of traditional metrics and the necessity for innovative methodologies that can capture the multifaceted nature of research activities and their impact on society and the economy. These challenges underscore the importance of developing advanced assessment methods to accurately measure research productivity and its alignment with economic and societal goals.

This study aims to evaluate the effectiveness of research and development activities in Kazakhstan, analyzing the relationship between R&D investments and scientific outputs across different periods.

2. METHODOLOGY

For the analysis of the effectiveness of R&D funding and the comparison of this effectiveness between five-year periods, Data Envelopment Analysis (DEA) was utilized. DEA is a non-parametric method used to evaluate the efficiency of various decision-making units (DMUs) based on their ability to transform multiple inputs into numerous outputs (Dilts et al., 2015). It provides a relative measure of efficiency based on the frontier of best performance, making it a suitable approach for analyzing the efficiency of scientific research activities (R&D) over time (Shero et al., 2022).

The application of DEA typically involves using standardized formulas, as demonstrated by equations (1) and (2).

$$Input = I = \sum_{i=1}^{I} u_i x_i , \quad (1)$$

where x_i is a given input, u_i is the specific weight assigned to said input, and weights are values between 0 and 1. The computation of virtual outputs is performed using the subsequent formula:

$$Output = J = \sum_{j=1}^{j} v_j y_j . \quad (2)$$

In this calculation, the weights assigned to the outputs (y_i) and inputs (v_j) are values ranging from 0 to 1. Notably, the resulting efficiencies are constrained to fall from 0 to 1. Efficiency is calculated by employing a function, denoted by equation (3), that takes into account the virtual inputs and virtual outputs (Shero et al., 2022):

$$Efficiency = \frac{J}{I} = \frac{\sum_{j=1}^{j} v_j y_j}{\sum_{i=1}^{I} u_i x_i} . \quad (3)$$

At this stage, the values for inputs and outputs for each decision-making unit are known, but the weights assigned to these inputs and outputs are not predetermined. Instead of using a single set of weights for each input and output, DEA permits each unit to have its unique set of weights for all inputs and outputs.

DEA is based on the concept of efficiency, defined as the ratio of the weighted sums of outputs to the weighted sums of inputs. In this study, DEA is used to evaluate the relative efficiency of scientific research activities in Kazakhstan over four separate five-year periods, providing insight into how effectively inputs are converted into outputs during each period.

It is crucial to note that the efficiency coefficient is only valid within the analyzed dataset. That is, it represents efficiency relative to other DMUs in the specific analysis and is not an absolute indicator of efficiency in a global sense. It is also important to acknowledge that DEA provides only relative efficiency indicators. Hence, a descriptive analysis was conducted to understand better the relationship between the efficiency of scientific activities and the funding of Kazakhstan's scientific sector. This analysis was based on the examination of quantitative data, including R&D expenditures, the ratio of R&D expenditures to the gross domestic product (GDP), the number of research organizations, the workforce involved in R&D, the proportion of these individuals holding academic or scientific degrees, the number of articles indexed in scientometric databases, and patents for inventions in Kazakhstan.

Data sources included the scientometric databases Scopus and Web of Science, the State Register of Inventions, Utility Models, Industrial Designs, Trademarks, Appellations of Origin of Goods, Selection Achievements of the Republic of Kazakhstan (http://gosreestr.kazpatent.kz/), and the Bureau of National Statistics of Kazakhstan (https://stat.gov.kz/).

A chronological aggregation of the data presented average values over four separate five-year intervals, allowing for a comparative temporal assessment. The conversion of research and development expenditures from the local currency (tenge) to USD was conducted based on the average exchange rate over five years.

The main focus of the analysis was on the outcomes of scientific work, quantitatively determined through the number of publications in the Scopus and Web of Science databases, as well as patent registrations. These outputs were juxtaposed with human capital indicators and R&D expenditures.

3. RESULTS

According to the official state statistics for 2022, 22,456 professionals were employed in the scientific sector, of which 18014 were researchers. Notably, 35% of this workforce hold academic or scientific degrees, including 1,713 Doctors of Science, 3,946 Candidates of Science, and 2,462 Ph.D.s (Bureau of National Statistics of Kazakhstan, n.d.). Table 1 provides the average indicators from 2003 to 2022 in five-year ranges, reflecting general scientific trends, including research and development expenditures, the ratio of R&D to GDP, and the number of personnel involved in this activity.

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Table 1. Patterns of change in key indicators in Kazakhstan's science

Key Indicators	2003–2007 Average	2008–2012 Average	2013–2017 Average	2018–2022 Average
Internal R&D expenditure, million tenge	19,877.2	40,364.4	66,561.5	94,895.8
USD/KZT rate five year daily average, tenge	133	149	245	405
Internal R&D expenditure, USD	14,945,263	27,090,201	27,167,959	23,431,062
Share of domestic R&D expenditures from gross domestic product, %	0.25	0.18	0.16	0.12
Number of organizations (enterprises) carrying out R&D, units	367	403	378	403
Number of employees performing R&D, people	17,908	17,505	23,861	22,191
Of which:				
research specialists	11,224	11,345	17,841	17,582
Of which:				
Doctor of Sciences	1084	1,234	1,832	1,744
Ph.D.	–	88	405	1,616
Candidates of science	2,949	3,104	4,911	4,144
The number of publications in the Web of Science database	1,468	2,316	10,561	20,532
The number of publications in the Scopus database	1,799	2,746	14,135	28,280
The number of publications in the Scopus database Open Access, units	252	533	3,456	13,462
Patents, units	6,968	6,576	5,597	2,612

The table analysis indicates that the number of organizations conducting research and development has generally increased slightly but experienced a decline from 2013 to 2017. These fluctuations may be related to funding, policy, and sector consolidation changes.

There is an observed growth in the total number of employees performing research and development, peaking in 2013–2017. However, a slight decrease in 2018–2022 may require further study to understand the reasons for this decline.

The number of specialist researchers has increased significantly, reaching a peak in 2013–2017, and then slightly decreased. The trend is similar to the total research personnel, indicating that researchers make up a significant portion of the workforce from research activities.

There is a clear trend of increase in internal R&D expenditures, which have risen from 19,877.2 million tenge on average for 2003–2007 to 94,895.8 million tenge on average for 2018–2022. This indicates significant investments in research and development over the years.

The efficiency of R&D funding and scientific production was evaluated using Data Envelopment Analysis (DEA) and descriptive analysis.

3.1. Assessment of the effectiveness of research and development (R&D) in Kazakhstan based on data coverage analysis

DEA, a non-parametric approach, assesses relative efficiency by comparing weighted sums of outputs to those of inputs. This study applies DEA to gauge the effectiveness of scientific research activities (R&D) in Kazakhstan across four distinct five-year periods, shedding light on the conversion efficiency of inputs into outputs during each interval.

For input data, R&D expenditures were considered to gauge financial investments, the number of R&D employees represented human capital, and the number of research organizations covered institutional breadth. Outputs included publications indexed in Scopus, chosen for its more extensive coverage of Kazakhstani-affiliated articles than Web of Science. Given the significant overlap between Scopus and Web of Science, this approach avoids redundancy from counting the same articles in multiple databases. Open access publications were also included as outputs to signify research accessibility and dissemination, while patent registrations were selected to measure the practical application and innovations stemming from R&D efforts. This selection ensures a balanced and comprehensive analysis, clarifying redundancy and excessive complications in the evaluation process.

Due to the different measurement units and magnitudes of the input and output data, normalization was necessary. This was achieved by dividing each input and output value by the maximum value observed in the dataset for that particular indicator, rescaling all data points to a uniform range from 0 to 1. In analyzing R&D efficiency in Kazakhstan, normalized coefficients of 1/3 were uniformly applied to all variables to maintain an egalitarian approach to valuation. This equal weighting assumes that each input and output has a comparable impact on the overall effectiveness of R&D activities, recognizing the absence of prior knowledge or specific criteria that would necessitate differential weighting. This method simplifies the analysis and provides a neutral comparison basis, allowing for an unbiased efficiency assessment across all measured dimensions.

The normalized data are presented in Table 2.

These values are normalized based on the maximum value for each output category across all periods, bringing all values to a scale from 0 to 1. This normalization facilitates a more equitable comparison of results across different periods.

The calculated efficiency scores, derived from the normalized input and output data, offer a quantitative measure of how effectively resources are utilized in the R&D sector (Table 3).

The efficiency ratings of scientific research activities in Kazakhstan during four successive five-year periods demonstrate a significant evolution in the sector's effectiveness. The 2008–2012 period is characterized by a decrease in efficiency rating compared to the previous period. Such a decline may indicate issues or transitional dynamics within the research and development sector, where an increase in input resources may not correspond to a proportional output increase. This could reflect a shift in priorities, economic factors, or the need for adjustment and alignment within the R&D infrastructure. However, a substantial increase to 0.531 in 2013–2017 and a significant jump to 0.850 in 2018–2022 reflect progressive steps towards optimizing research activities. This might result from cumulative improvements in research practices, better alignment of research with national and global priorities, or improved integration of research outcomes with market and societal needs. A descriptive analysis will provide a deeper understanding of the relationship between R&D funding and scientific production.

3.2. Descriptive analysis of the dynamics of key indicators in Kazakhstan's science from 2003 to 2022

Despite the increase in absolute terms, the share of R&D expenditures in GDP decreases from 0.25% to 0.12%. This indicates that the growth in R&D spending is not keeping pace with econom-

Table 2. Normalized data of indicators used as Inputs and Outputs in the Data Envelopment Analysis

Indicator	2003–2007	2008–2012	2013–2017	2018–2022
Input				
Internal R&D expenditure, USD	0.550	0.997	1.000	0.862
Number of employees performing R&D, people	0.751	0.734	1.000	0.930
Number of organizations (enterprises) carrying out R&D, units	0.911	1.000	0.938	1.000
Output				
The number of publications in the Scopus database, units	0.064	0.097	0.500	1.000
The number of publications in the Scopus database Open Access, units	0.019	0.040	0.257	1.000
Patents, units	1.000	0.944	0.803	0.375

Table 3. Efficiency indicators for each period

Period	Efficiency
2003–2007	0.489
2008–2012	0.396
2013–2017	0.531
2018–2022	0.850

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ic growth, or it could mean that the economy is growing faster than investments in R&D. This deserves attention considering that the Kazakhstan Strategy 2030 (Nazarbayev, 1997) set a goal to allocate 1% of GDP to research and development by 2015. The government and institutions may need to evaluate the strategic importance of research activities to ensure adequate funding relative to the country's economic development. With adjustments for the exchange rate to the US dollar, the investment model maintains its upward trajectory throughout the 2013–2017 years, after which a slight decline is observed in the 2018–2022 period.

From 2003 to 2022, the Scopus database recorded 46,960 articles affiliated with institutions in Kazakhstan, while Web of Science indexed 34,877 articles during the same period (Figure 1). The primary trend is a clear and consistent increase in the number of publications in both databases.

From 2003 to 2022, publications in Scopus more than quadrupled, increasing from 367 to 6,536, while Web of Science publications also saw a substantial rise, growing from 300 to 4,222. The expansion is more pronounced in the Scopus database, which may be due to its broader coverage and inclusion criteria compared to Web of Science.

The period from 2011 to 2022 is particularly noteworthy for its rapid increase, suggesting a potential acceleration in research output and possibly investments in research and development. Minor fluctuations in Web of Science figures in 2020 could be attributed to external factors, such as the global impact of the COVID-19 pandemic, which may have influenced research publication patterns.

The analysis of data regarding the average number of publications per researcher and the average cost of one publication is presented in Figure 2.

From 2003 to 2022, we can observe a significant increase in the average number of publications published per researcher. This indicates increased scientific productivity among researchers in Kazakhstan over the years.

At the same time, there is a noticeable decrease in the average cost of a publication in tenge, which suggests an increase in the efficiency of research funding, leading to a reduction in the cost of one published article. This could be related to various factors, such as more efficient use of funds, economies of scale, or increased publications that do not require a proportional expense increase.

According to data from InCites, an analytical tool in the Web of Science Core Collection database, Kazakhstan released 12,200 publications from 2019 to 2021, constituting 0.12% of the total number of publications in the Web of Science Core Collection. This indicator ranks Kazakhstan 76th in the world out of 213 countries. However, Kazakhstani publications' normalized average citation rate is 0.76, below the global average of 1.0.

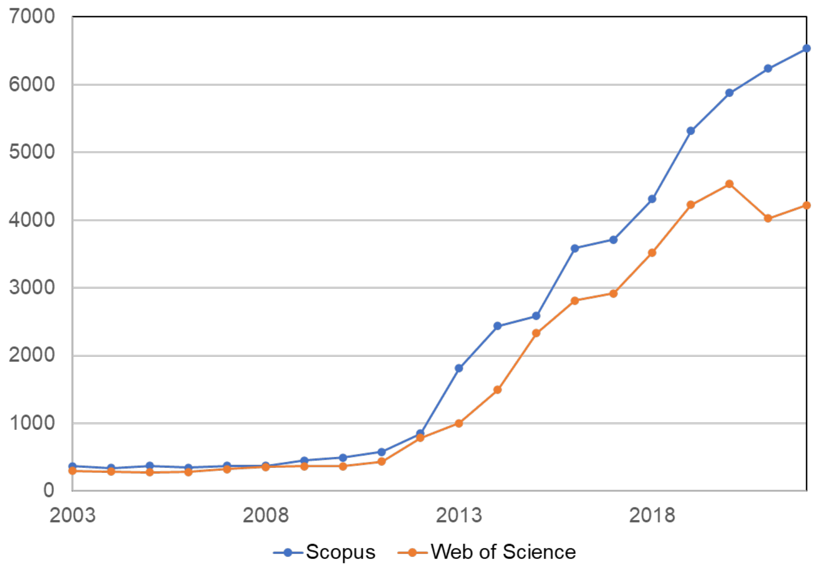

Figure 1. Number of publications affiliated with Kazakhstani institutions from 2003 to 2022

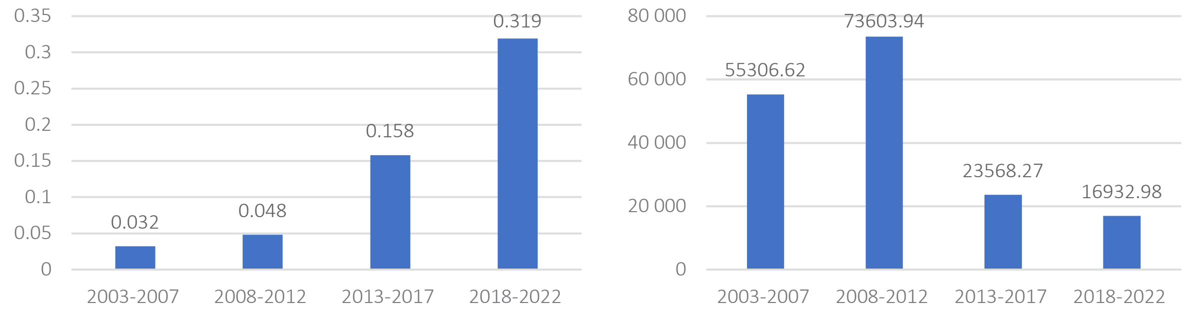

Figure 2. Analysis of data regarding the average number of publications (Scopus) per researcher and the average cost of one publication

The analysis of Kazakhstan's gross expenditure on R&D across various scientific fields—natural, technical, medical, agricultural, public, and humanitarian—reveals an overarching trend of increasing investment in research and development across almost all domains. The technical field consistently receives the most funding, peaking at 48,881.2 million tenge in 2022, reflecting the country's focus on technological advancement and its potential alignment with industrial and economic objectives. The natural sciences also witness a significant increase, indicating their potential strategic importance to the country's developmental agenda. Figure 3 illustrates the gross expenditure on R&D by the field of science.

Figure 4 demonstrates the ratio of costs for applied research to costs for basic research across four separate five-year periods.

From 2003 to 2022, the funding ratio for applied research versus basic research in Kazakhstan underwent notable fluctuations, indicating strategic shifts in research activities. Initially, this ratio was 1.56 in 2003–2007, emphasizing a greater focus on applied research. This focus intensified in 2008–2012 when the ratio increased to 3.02, possibly reflecting strategic aspirations for immediate innovation aligned with market demands. In the subsequent period, 2013–2017, the ratio decreased to 2.58, signaling a recalibration towards basic research. However, in 2018–2022, the ratio increased to 3.71, highlighting renewed and robust attention to applied research, likely in response to global trends that value the rapid application of scientific discoveries. Despite these variations, the overall trend underscores a progressive bias towards applied research, reflecting Kazakhstan's evolving strategic approach to fostering research aligned with practical and market needs.

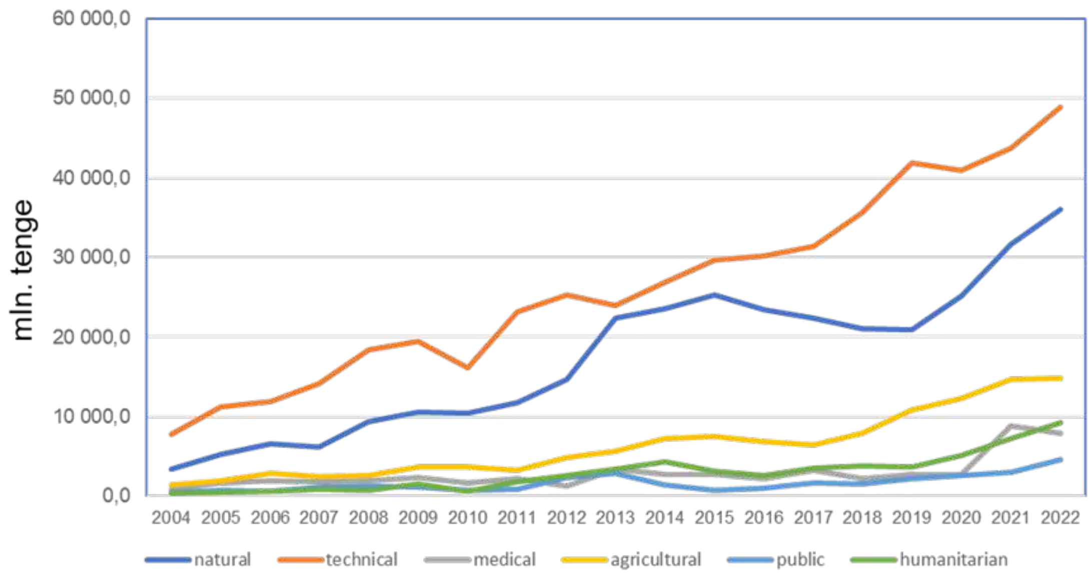

Figure 3. Gross expenditure on R&D by field of science

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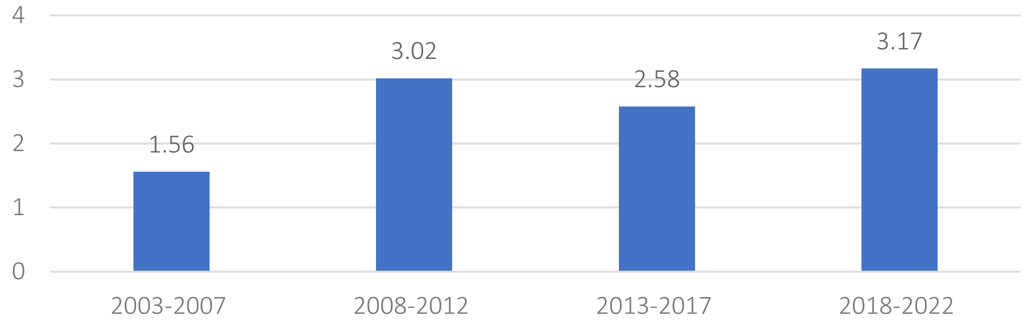

Figure 4. The ratio of costs for applied research to costs for basic research across four separate five-year periods

While the coefficients indicate relative financial emphasis, they do not inherently reflect the research's impact, quality, or outcomes. To fully comprehend this ratio, it should be examined alongside scientific output indicators such as patent applications and scholarly publications.

In Scopus-indexed publications, Engineering leads with 10,712 articles, signifying substantial attention to this field, often directly linked to industrial application and technological advancement (Figure 5). Physics and astronomy are closely followed with 8,224 articles, emblematic of foundational scientific research capable of driving technological breakthroughs. Social Sciences with 7,343 articles and Materials Science with 6,584 articles also hold significant positions, portraying a wide spectrum of research encompassing both applied and fundamental science, indicative of a comprehensive scientific endeavor in the country.

In contrast, the trend in the number of invention patents is declining over time (Table 1). The average number of patents starts significantly in 2003–2007 with 6,968 patents, potentially reflecting a period of intense innovation or favorable conditions for patenting inventions. However, there is a gradual decrease in each subsequent period, culminating in an average of 2,612 patents in the 2018–2022. This decline could result from various factors such as changes in patent law, shifts in research focus, or a transition to publishing instead of patenting.

The discrepancy between the growth in publication volume and the decline in patent activity might indicate that while academic and theoretical research outputs are increasing, they are not proportionally converted into patented inventions. This could point to improved mechanisms to facilitate the transition from research to com-

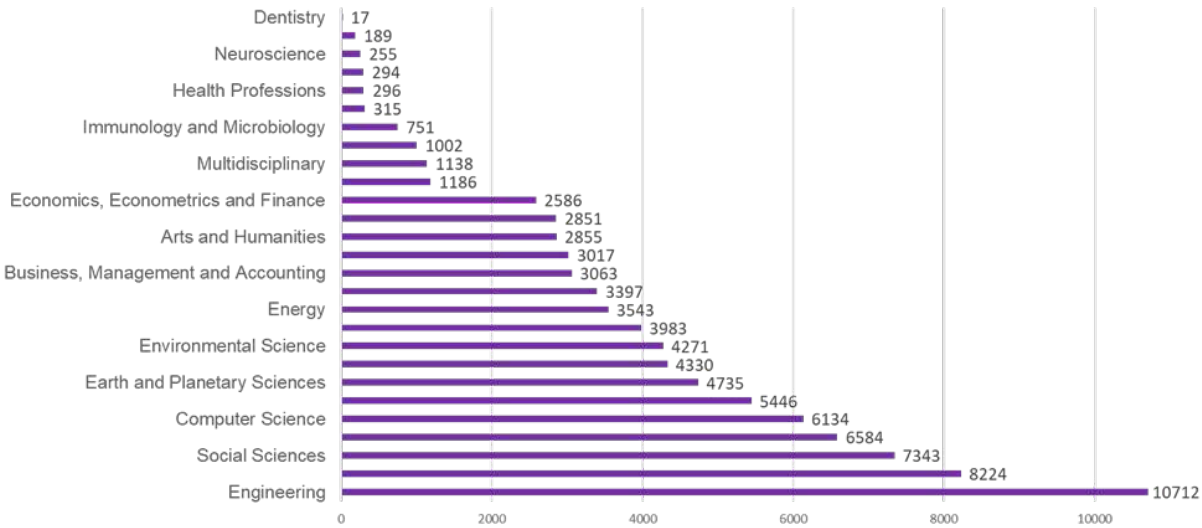

Figure 5. The distribution of Kazakhstan-affiliated publications in the Scopus database across various research fields from 2003 to 2022

mercial application, better integration of academic research with industry needs, or enhanced support for innovations that lead to patentable technologies.

The observed discrepancy between the increased allocation of funds for applied research and the declining trend in patent registrations in Kazakhstan highlights a critical gap in the innovation system. While the ratio of funding is increasingly favoring applied research, indicating a strategic intent to foster research with immediate practical implications, the reduction in the number of patents points to a potential shortfall in translating this research into tangible innovations. This is corroborated by the fact that Kazakhstan currently occupies lower positions in global science and innovation rankings. The 2022 Global Innovation Index (GII) ranks 83rd out of 132 countries, scoring 27 points. This comprehensive index evaluates 82 variables that represent the innovative capacities of nations, encompassing aspects such as the political climate, education, infrastructure, and business development.

4. DISCUSSION

The findings of this study offer insights into the dynamics of research funding and scientific output in the country.

A significant increase in research funding over these two decades was paralleled by a growth in scientific publications, as evidenced by Scopus-indexed articles. This trend is consistent with a broader understanding in the literature on scientific research funding, where an increase in investments often correlates with enhanced productivity in terms of publications (Ebadi & Schiffauerova, 2016). However, it is essential to note that while funding plays a key role, it is not the sole driver of scientific output. The complexities of the scientific research and publication processes, including changes in academic standards, international collaborations, and the evolving nature of scientific inquiries, also significantly contribute to these outcomes (Cimini et al., 2016).

Comparing the current findings with previous studies reveals similar trends in other developing economies, where increased R&D investment has led to a rise in publication outputs (Ramírez-Castañeda, 2020). Nevertheless, Kazakhstan's unique socio-political and economic context provides a distinct backdrop for these results. The study's data on the fluctuation of organizations conducting R&D and the slight decrease in R&D personnel in recent years add complexity to the straightforward narrative that funding equals productivity. Not extensively covered in previous studies, this aspect opens new avenues for understanding the nuanced relationship between funding and scientific research outcomes.

Furthermore, the analysis indicates the need for a more comprehensive approach to the development of science in Kazakhstan. The observed gap in the scientific structure, as highlighted by lower rankings in global science and innovation indices, suggests that mere financial investments are not enough. Strategic alignment of research activities with national goals and industry needs, effective management, and robust support systems are essential for transforming financial inputs into impactful scientific results.

Despite increased investments in applied research, the decrease in the number of patent registrations may indicate issues in transforming research into commercialized products or technologies. This could result from insufficient integration between research institutions and industry or an inadequate infrastructure supporting innovation and patenting. It might also reflect a shift in applied research towards areas less likely to yield patents or a preference for theoretical research over practical application.

Regulatory and administrative hurdles could also play a role, making the patenting process cumbersome and less appealing to researchers. Moreover, the academic culture may favor publications over patents, guided by academic incentives prioritizing scholarly output over commercial innovations.

Addressing this discrepancy requires a comprehensive strategy. Strengthening collaboration between industry and academia could ensure that research is more aligned with market needs, facilitating the transition of ideas into marketable products. Providing better support for innovation, including resources for prototype development, patent support programs, and technology incubators, can help bridge the gap between research and commercialization. Simplifying the patent application process

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by reducing bureaucratic barriers and costs could encourage more researchers to pursue patents. Finally, ensuring a balanced incentive system that recognizes the value of patents and publications can foster an environment where scientific research contributes optimally to economic growth and societal development.

By tackling these issues, Kazakhstan can realign its investment in applied research with its innovation outcomes, ensuring that the strategic focus on applied research effectively translates into impactful and market-relevant innovations.

Research institutions globally are navigating intense competition for resources, including intellectual capital and funding. To optimize resource usage and foster innovation, decision-makers increasingly adopt competitive funding models alongside traditional methods (Lepori et al., 2007). This shift indicates the necessity to diversify the pathways of science funding, such as grants, scholarships, contracts, and agreements. Each funding stream offers unique advantages and can contribute to various aspects of scientific progress.

Grants, a prevalent funding tool, support specific research projects financially. They have been shown to boost scientific progress, with grant recipients often achieving higher productivity and societal impact through influential publications and research results (Khamis et al., 2018; Hussinger & Carvalho, 2021). Grants also encourage collaboration and knowledge exchange, requiring interdisciplinary or international partnerships. However, the competitive nature and complex application processes can limit access for some researchers (Bennett & Gadlin, 2012; Paterlini, 2023).

Scholarships support individual researchers, aiding research activities, career development, and education. They offer scholars time and resources to focus on their studies, leading to significant field contributions. Scholarships foster independence, networking, and professional growth, often including mentorship and training (Iglič et al., 2017; Lachmann et al., 2020). For early-career researchers, scholarships positively impact academic success and research outcomes, promoting diversity and inclusion in research careers (Pascarella & Terenzini, 2005; Nazah et al., 2022; Karlin et al., 2022).

Contracts and joint research agreements between academia and industry are key funding tools, enhancing knowledge transfer and commercialization (Martin-Sardesai et al., 2019). These collaborations offer access to resources and expertise, although they raise concerns about conflicts of interest and industry influence on research (Ankrah & Tabbaa, 2015).

Seed funding is vital for pioneering research, supporting innovative ideas that might not qualify for traditional funding (Contopoulos-Ioannidis et al., 2003). It often focuses on interdisciplinary and high-risk/high-reward projects, though long-term impact and scalability are challenges (Xia et al., 2022).

Financial agencies, both public and private, are central in distributing resources for research, setting priorities, and evaluating grants. Their role in advancing scientific excellence and fostering innovation is crucial, with effective agencies emphasizing transparency and clear funding criteria (Van der Lee & Ellemers, 2015). These institutions also facilitate collaboration and contribute to the research ecosystem's growth (Rijcke et al., 2016).

Research councils, key in specific or interdisciplinary research areas, guide research agendas and allocate resources based on societal and economic impacts (Temel et al., 2021). Universities and research institutions nurture talent and knowledge, fostering research excellence and interdisciplinary collaboration (Etzkowitz et al., 2000; Rowlinson et al., 2014).

Governmental bodies and ministries at the national level shape research landscapes, aligning activities with national priorities and collaborating with financial agencies (Bonaccorsi et al., 2022). International and supranational institutions, like the European Union Framework Programmes, play a growing role in global research coordination and funding, promoting international cooperation (Planes-Satorra & Paunov, 2017; Lam, 2011).

Developing these diverse funding streams is crucial for building a solid and dynamic scientific ecosystem. By adopting a multifaceted approach to funding, countries can better address the complex challenges of modern research, foster an innovative culture, and enhance their competitiveness in the global scientific community.

Future research should focus on the qualitative aspects of scientific output, examining not just the quantity but also the quality and impact of research. Investigating factors such as citation impact, international collaboration, and the role of policy changes in shaping scientific output can provide a more comprehensive understanding of the evolution of the scientific sector.

CONCLUSIONS

The study evaluated the effectiveness of R&D activities in Kazakhstan by exploring the dynamics between R&D investments and scientific outputs across distinct five-year periods. The analysis demonstrated a substantial increase in R&D expenditure from 149 45263 USD in the 2003–2007 average to 23,431,062 USD in the 2018–2022 average. However, this increase was not proportional to the country's economic growth, as the share of domestic R&D expenditures from the gross domestic product decreased from 0.25% to 0.12% during the same period.

Regarding scientific output, the study revealed a significant increase in publications in both the Web of Science and Scopus databases. The number of Scopus publications saw a remarkable rise from 1,799 in 2003–2007 to 28,280 in 2018–2022, with the Open Access publications also increasing substantially from 252 to 13,462. This publication growth indicates enhanced scientific productivity and broader dissemination of research findings.

Contrastingly, the number of registered patents showed a declining trend, decreasing from an average of 6,968 patents in 2003–2007 to 2,612 in 2018–2022. Despite the increased funding for applied research, this decline points to potential gaps in the innovation system, where increased research activity is not commensurately translating into patentable inventions.

These findings underscore the need for a comprehensive approach to bolster the nation's innovation ecosystem. While Kazakhstan has made commendable progress in increasing research funding and scientific publication output, the decreasing trend in patent registrations and the decline in R&D expenditure relative to GDP call for strategic interventions. These should include fostering more vital industry-academia collaboration, enhancing innovation support infrastructure, streamlining the patenting process, and establishing a balanced incentive system that values scholarly publications and patentable inventions. Addressing these challenges will be pivotal in ensuring that substantial R&D investments enhance scientific research and contribute effectively to market-relevant innovations and the nation's socio-economic development. These conclusions guide policymakers, researchers, and other stakeholders in shaping future strategies to enhance the scientific landscape.

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