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Analysing the Efficiency of Scientific Potential in Driving National Competitiveness: Evidence from Emerging Economies and the Case of Kazakhstan

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Abstract:

In the context of the global transformation toward a knowledge-based economy, the effective mobilization and assessment of scientific potential has become a decisive factor in strengthening national competitiveness. This study highlights the growing importance of evidence-based public science policy that incorporates international benchmarks while accounting for national socio-economic characteristics.

The purpose of the research is to provide a comprehensive analysis of scientific potential and its role in enhancing economic competitiveness, using Kazakhstan as a case study. The research examines the structure and dynamics of research and development (R&D) funding, the spatial distribution of resources, the roles of the public and private sectors in building scientific infrastructure, and lessons from global models of science policy and governance. Although the study is grounded in the Kazakhstan context, its analytical framework and conclusions are designed to be relevant and transferable to other emerging and transition economies facing similar institutional and developmental challenges. Methodologically, the study applies systemic and institutional approaches alongside economic and statistical tools, including trend, correlation, cluster, and comparative analyses. Based on data from 2020–2024, the research identifies core barriers such as underdeveloped private sector investment, fragmented science-business integration, and regional disparities in research activity. It confirms a positive correlation between regional R&D expenditure and competitiveness metrics. The findings suggest that aligning national scientific development with international best practices, through targeted investments, policy reform, and cross-sector collaboration, can significantly improve innovation ecosystems and economic resilience in comparable global contexts.

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Keywords: scientific potential; economic competitiveness; research and development; innovation policy; emerging economies.

JEL Classification: O32; O38; R11; H52.

Introduction

In the context of a rapidly developing global economy and technological transformations, scientific potential is becoming a key factor in sustainable growth, innovative development and increasing the competitiveness of the country. The modern economy is increasingly based on knowledge, intellectual capital and the ability to create and implement advanced developments. The relevance of the study is due to the need to form an effective national scientific policy aimed at developing intellectual resources, improving scientific infrastructure and stimulating applied research. In the context of global challenges associated with the transition to a new model of economic growth based on innovation and sustainable development, the role of science is increasing many times over. Kazakhstan needs to clearly define the current state and potential of its scientific sphere in order to make informed management decisions.

The practical significance of the study lies in the applicability of its results to the development of national and regional strategies for scientific and technological advancement, the optimization of budgetary and extra-budgetary funding for science, the formation of effective mechanisms for interaction between science, education, and business, and the enhancement of R&D efficiency through the integration of scientific outputs into the real sector of the economy.

The originality of this research stems from its integrated examination of how scientific capacity influences national economic competitiveness, with a particular focus on a country representing the characteristics of many emerging and transitional economies. By employing Kazakhstan as a reference point, the study offers insights into the effectiveness of various policy and investment approaches in the development of national science systems. The research introduces a multidimensional set of evaluation criteria, both quantitative and qualitative, that allow for a nuanced analysis of research infrastructure, regional disparities, and policy outcomes. These are juxtaposed against selected international practices to extract relevant lessons and adaptive mechanisms.

The study's methodological framework is guided by a set of empirically testable assumptions concerning the determinants of scientific and innovation performance. The analysis examines the effects of public and private R&D expenditure on scientific output, measured through publication activity and patenting rates. Regional R&D capacity is operationalized using indicators of investment intensity and research personnel, and its relationship with regional economic performance is assessed using statistical methods.

Particular attention is given to institutional factors influencing knowledge commercialization, especially the degree of interaction between research organizations and industry. The study further evaluates the impact of investment in research and higher education infrastructure on innovation outcomes and international innovation rankings. Drawing on international experience, the analysis incorporates co-financing models involving public and private stakeholders to assess their contribution to the efficient use of national research resources. Finally, the role of academic institutions in applied research and collaborative projects is examined as a driver of technological advancement and innovation system development.

Overall, the study supports the conclusion that scientific potential, if reinforced through institutional modernization, regionally inclusive policies, and international cooperation, can function as a key pillar in shaping long-term economic resilience and global competitiveness in contexts marked by structural transformation.

This paper draws on the tenets of endogenous economic growth theory, which views scientific potential not as the result of budget funding alone, but as a process of accumulating human, technological, and institutional capital that shapes the long-term trajectory of GDP growth and determines the structural transformation of the economy (Howitt, 2010). In this context, the mobilization of scientific potential is a key factor in enhancing national competitiveness, industrial diversification, and the formation of innovative markets.

Based on these theoretical principles, this article provides a comparative analysis of international experience, in particular the Finnish model of scientific and innovative development. This analysis demonstrates that the effectiveness of the scientific sphere is determined not so much by absolute funding volumes as by the level of institutional coordination, a focus on the commercialization of scientific results, and the active participation of the private sector in the financing and implementation of R&D. The findings allow us to draw a reasonable conclusion that for the Republic of Kazakhstan, the key direction for increasing the return on scientific potential should be the transition from a quantitative increase in budget expenditures to a qualitatively oriented model of science management aimed at strengthening the interaction of science and business, increasing the innovative activity of the private sector, and increasing the contribution of scientific research to economic growth and the international competitiveness of the country.

1. Research Methods

To achieve the stated objectives of the study, a set of interrelated methods was used, aimed at a comprehensive analysis of the current state, identifying factors influencing scientific and innovative development, and formulating recommendations for improving the efficiency of using the country's scientific potential.

The methodological basis was formed by the provisions of the systemic, institutional and innovative approaches, allowing us to consider science as an integral part of the socio-economic system. The main attention was paid to the integration of quantitative and qualitative methods of analysis, which provided a comprehensive approach to studying the relationship between scientific potential, investment in R&D and the level of competitiveness of the national economy. The study applied statistical, regression, and cluster analysis, as well as benchmarking and expert assessment. Analytical methods were used to examine theoretical concepts and Kazakhstan’s regulatory framework. Statistical analysis processed data on science funding, researchers, patents, and R&D levels. Correlation and regression identified relationships between R&D funding, researchers, publications, patents, and regional competitiveness. Cluster analysis grouped Kazakhstan’s regions by scientific and innovative development. Benchmarking compared Kazakhstan’s experience with international practices (e.g., South Korea, China, Finland). Expert assessments summarized opinions from specialists in science, education, and policy. Trend analysis was used to forecast the development of scientific potential indicators.

The study utilized statistical and mathematical economic methods, including trend analysis, linear trend modeling, time series anomaly testing (Irwin's test), trend assessment, and model adequacy and accuracy analysis. The resulting regression models allow for a quantitative assessment of the efficiency of scientific resource utilization and the generation of forecast estimates with confidence intervals. To further deepen the analysis, the article proposes the use of efficiency assessment methods such as data envelopment analysis (DEA) or panel regression. This will enable comparisons of scientific potential utilization across countries and regions, as well as identifying factors influencing the return on R&D investment.

2. Research Background

In a modern knowledge-based economy, the capabilities of the national research system are a key factor in the competitiveness and socio-economic development of the country (Abramo & D’Angelo, 2024). The determining factor in the innovative development and competitiveness of the national economy is the intellectual potential of all levels of the socio-economic system, including the regional one, which generate technological innovations and create opportunities for the country's transition to a higher level of technological structure, which becomes a decisive factor in the competitiveness of the national economy (Fisunenko & Ziuzia, 2021).Competition is an important factor contributing to the prosperity of the economy. Competition contributes to improving the quality of services, privatization of public services and the creation of a more favorable business environment, promoting economic growth (Lee et al., 2016).

Innovation, encompassing both product and process innovation, is crucial for enhancing competitiveness, driving growth and promoting sustainability in the modern economy. The digital economy is the strategic contextual frame for this study (Sorescu & Schreier, 2021; Hanna, 2020). In the 21st century, the digital economy is a transformative force that is changing industries, markets and business models. Many experts emphasize how difficult it is to accurately assess an economy that is defined by rapidly evolving goods and services in an innovative environment (Zeynalli, et al., 2022). The digitalization of economic activities and the impact of digital technologies on economic development are important factors in transforming the scientific landscape (Xu & Weidong, 2022; Yu et al., 2023). UNCTAD suggests that governments should promote the scaling up and dissemination of successful innovations with the active participation of civil society, especially the private sector, to make innovative results accessible to marginalized and vulnerable communities.

In the context of globalization, key elements of innovation such as talent, knowledge and technology are rapidly spreading around the world, providing good opportunities for international innovation cooperation. Many studies have documented that innovation cooperation between countries can not only increase the value and quality of innovation outputs (Bercovitz & Feldman, 2011), but also expand the channels for underdeveloped countries to achieve technological catch-up development and exceed their targets through international knowledge spillovers (Giuliani et al., 2016). A distinctive feature of R&D funding in leading foreign countries is that it is largely carried out by the private sector. In terms of the share of private expenditure on R&D, the undisputed leaders are Japan (76.5%), South Korea (74%), and China (74%). The top ten also includes Taiwan (72.5%), Switzerland (68%), Finland (67%), Germany (66%), Australia (62%), Belgium and Denmark (60% each), and the United States (58%) (Gulbrandsen & Kyvik, 2015).

One can consider various strategic planning tools needed for research support. If this is considered from the perspective of providing quality higher education, then one can consider the process of implementing an interactive tool for creating a digital curriculum (Wijngaards-de Meij & Merx, 2018). There is a lack of empirical research in the field of research support, as well as theoretical contributions that help us better understand the role and significance of this research by conducting research and sharing not only success stories but also reports of failures (Laksov & McGrath, 2020; Sutherland, 2018). To explain what regions, need to accumulate scientific capacity and maintain decades of dominance, it is often argued that a minimum number of researchers, a critical mass, is required to grow and create self-sustaining capacity (Groot & García-Valderrama, 2006). In addition to the attractiveness of the region and the everyday environment, the scientific environment and innovation potential play an important role. Financing of scientific research and development in the leading countries of the world is characterized by a significant role of the private sector. The leaders in the share of private spending on science are Japan, South Korea, China, as well as Taiwan, Switzerland, Finland, Germany, Australia, Belgium, Denmark, and the USA (Morris et al., 2025). Gök et al. (2016) analyzes the impact of public funding on scientific results in Kazakhstan, which is directly related to the assessment of the effectiveness of regional scientific communities based on the analysis of public funding data for science.

Sun et al. (2023) explore how government funding influences innovation and research efficiency in developing nations, highlighting government's role in bridging gaps, promoting technology, and fostering innovation ecosystems, but also noting potential issues like dependency or inefficiencies, with findings generally supporting public R&D for national capacity building, especially in supporting SMEs and foundational research. Cao (2020) focuses on the assessment of scientific activity in countries with transition economies, which is relevant for regional scientific communities. Dobrzanski & Bobowski (2020) examine the relationship between government support and innovation potential in ASEAN economies and Choi et al. (2023) empirically investigate the effect of science, technology, and innovation official development assistance on the innovative capacity of developing countries, attempted to examine the moderating effects of R&D investment and its effect on innovative capacity.

Today, for quite a long time, many technology companies, including in Kazakhstan, have been cooperating with universities and the Ministry of Education to change and adapt educational programs to business needs, create opportunities for additional education, internships in companies (Wang et al., 2020). Kimeto (2021) argues that improving the skills and knowledge of the workforce can increase competitiveness and help create and maintain a viable industry.

According to the authors, Kazakhstan has significant potential for building a competitive innovative economy, but this potential has only been partially realized so far. Problems such as fragmented scientific infrastructure, weak involvement of the private sector and limited academic autonomy require systemic solutions. This is confirmed by foreign experience of scientific potential and competitiveness (Table 1).

Table 1. International experience in scientific potential and competitiveness in Kazakhstan

№	Country	Experience	A Lesson for Kazakhstan
1	South Korea: An R&D-Driven Economy Model	▪ the share of GDP allocated to R&D: ~4.9% (one of the highest in the world); ▪ the private sector finances more than 75% of scientific developments (Samsung, LG, Hyundai have their own research centers) ▪ the national innovation system is supported through grant programs of the Ministry of Science and ICT and the introduction of science parks and commercialization centers; ▪ the Brain Korea 21 program is aimed at training world-class researchers and attracting young scientists	▪ actively attracting private investment and creating conditions for R&D in business
2	Germany: Strong links between science and industry	▪ Fraunhofer Institutes are a unique network of applied research, financed 30% from the state budget and 70% from industrial orders; ▪ the technology transfer mechanism ensures a direct link between universities and industry; ▪ scientific personnel are trained within the framework of the "dual" education system, including practical training at enterprises	▪ development of applied science and cross-sector partnerships
3	Finland: Efficient Science with Few Resources	▪ scientific policy is formed through the Council for Science and Innovation Policy, subordinate to the Prime Minister; ▪ TEKES (Business Finland) operates in the country - an organization that supports small and medium-sized innovative companies; ▪ universities are autonomous and participate in business projects, receiving income from patents and contract R&D	▪ ensure autonomy of universities and flexibility in attracting funding
4	USA: Competition and the Grant System	▪ scientific research is developed through the mechanism of grants provided by organizations such as NSF, NIH, DARPA; ▪ universities are independent research centers, with about 60% of R&D being funded by private companies; ▪ universities cooperate with venture capital, especially in the field of start-ups, life sciences, AI	▪ building a competitive grant system and promoting universities as innovation centers
5	China: Centralized Accelerated Development	▪ R&D investments – more than 2.6% of GDP (with an upward trend); ▪ state mega-platforms for R&D have been created (for example, the "Made in China 2025" and "Scientific Power" projects); ▪ great attention is paid to technological sovereignty and training of personnel in STEM fields	▪ priority technological directions should be determined by the state and accompanied by a personnel policy

Source: compiled by the authors

The conducted analysis, as well as international experience, demonstrate that:

- A developed R&D system directly affects the level of technological independence and innovative activity. Leading countries (USA, Germany, South Korea, China) provide funding for scientific research mainly through the private sector, effectively combining state support with market mechanisms.
- It is important for Kazakhstan not only to increase state funding for science, but also to develop mechanisms for attracting business to the scientific agenda: to stimulate the creation of corporate research institutes, to launch joint research projects of universities and private companies.
- The formation of a critical mass of researchers, support for young scientists, the development of international scientific cooperation and the digitalization of scientific activity are a necessary condition for increasing the efficiency of the country's scientific ecosystem.
- Science should not be an isolated sphere, but an integrated part of the national economy, capable of generating applied solutions for business, the social sphere and public administration.

Thus, scientific potential is not just an intellectual resource, but a strategic capital that determines Kazakhstan's place in the global economy and forms the basis for technological and social progress. To enhance the country's competitiveness, it is necessary to systematically and balanced develop the scientific infrastructure, focused on results, innovation and integration into the global scientific space.

An analysis of modern scientific literature suggests that, in a knowledge economy, scientific potential is becoming a key factor in national competitiveness and sustainable socioeconomic development. Scientific potential should be viewed not as a sum of budget expenditures on research and development, but as the result of the accumulation of human, technological, and institutional capital capable of generating long-term economic growth and structural transformation. In this context, innovation, digitalization, and competition form a unified system of factors determining a country's ability to adapt to global technological change.

At the same time, according to the authors, a key issue for Kazakhstan is the gap between the growth of public funding for science and the actual economic returns from scientific activity. Unlike leading innovative economies, where the private sector is the primary driver of R&D, Kazakhstan's scientific system remains highly dependent on budgetary resources and insufficiently involves businesses in shaping the scientific agenda and commercializing research results. This reduces the effective use of scientific potential and limits its contribution to productivity growth and economic diversification. A significant limitation is also the fragmentation of scientific infrastructure and regional asymmetry in the distribution of scientific resources, which hinders the formation of a critical mass of researchers and sustainable scientific growth centers. Insufficient academic autonomy, weak technology transfer mechanisms, and limited university-business interaction hinder the transformation of scientific results into marketable innovations. Furthermore, despite the active digitalization of economy, digital technologies have not yet been fully integrated into the management of scientific activity and assessment of its effectiveness.

The prevalence of a quantitative approach to assessing scientific activity, focused on funding volumes and formal indicators, remains a problem, while results such as patents, startups, technological solutions, and impact on GDP remain secondary. This contrasts with international practice, which prioritizes productivity, competition for resources, and the alignment of science with market and societal demands. Thus, Kazakhstan's scientific potential offers significant potential for enhancing national competitiveness; however, its realization is constrained by institutional, structural, and economic constraints. The key challenge is the transition from a predominantly state-oriented model of scientific development to an integrated innovation system based on a combination of market incentives, private investment, international cooperation, and results-oriented management. Without addressing these issues, scientific potential risks remaining primarily an intellectual resource, failing to transform into sustainable competitive advantages for the economy.

3. Analysis and Research Results

The analysis of research and development (R&D) financing from the republican budget of the Republic of Kazakhstan over the period 2020–2023, complemented by trend modeling for 2024–2026, reveals a sustained increase in public investment, particularly in grant-based and program-targeted funding instruments (Table 2).

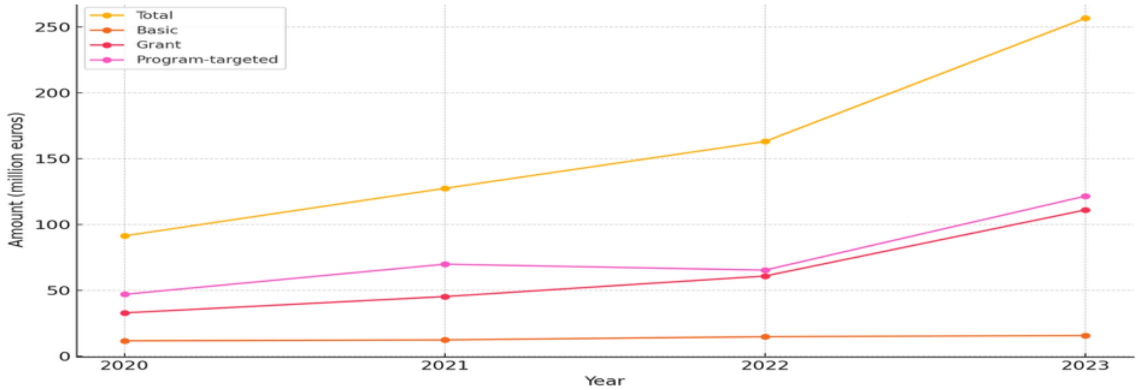
Table 2. Analysis of financing, million euros

Indicator	2020	2021	2022	2023
Total from the republican budget, of which:	91.3	127.4	163.0	256.6
– basic	11.6	12.3	14.7	15.6
– grant	32.8	45.2	60.8	111.0
– program-targeted	46.9	69.8	65.3	121.5

Source: compiled by the authors according to https://stat.gov.kz/ru/

As shown in Table 2 and illustrated in Figure 1, total R&D funding from the republican budget increased from €91.3 million in 2020 to €256.6 million in 2023, representing nearly a threefold rise. This growth was driven primarily by grant funding, which expanded from €32.8 million to €111.0 million (+238%), and program-targeted funding, which increased from €46.9 million to €121.5 million (+159%). By contrast, basic funding followed a more moderate and stable trajectory, rising from €11.6 million to €15.6 million (+34.5%).

Figure 1. Financing of R&D from the republican budget



Source: compiled by the authors according to https://stat.gov.kz/ru/

A particularly sharp acceleration occurred between 2022 and 2023, when grant funding grew by 82.6% and program-targeted funding by 86.2%, reflecting a strategic shift toward competitive and mission-oriented financing mechanisms. Basic funding increased by only 6.1%, confirming its stabilizing rather than expansionary role in the R&D financing structure.

To assess the underlying dynamics, linear trend models were estimated for each funding component using euro-denominated data for 2020–2023. The general form of the model is: $y = a + bt$, where y denotes the volume of funding and t represents time (year). The estimated models and coefficients of determination are presented in Table 3.

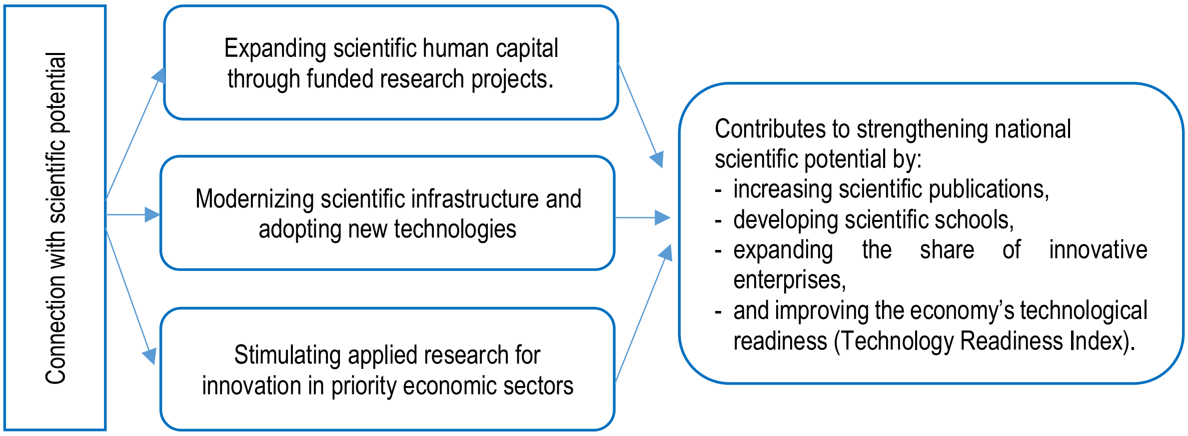
Table 3. Constructed linear models

Direction	Trend Equation	Coefficient of determination R^2
Total	$y = -107.28 + 49.16 \cdot t$	0.934
Basic	$y = -28.82 + 2.28 \cdot t$	0.954
Grant	$y = -50.53 + 23.33 \cdot t$	0.885
Program-targeted	$y = -44.23 + 21.92 \cdot t$	0.783

Source: compiled by the authors

The results indicate stable upward trends across all funding categories, with the basic funding model exhibiting the highest explanatory power ($R^2 = 0.954$). Grant and program-targeted funding also show strong positive trends, confirming the growing importance of competitive instruments in Kazakhstan's science financing system. Increased R&D funding directly supports the development of scientific potential by expanding human resources, modernizing research infrastructure, and stimulating applied research, as shown in Figure 2.

Figure 2. Relationship with scientific potential



Source: compiled by the authors

Further insights are provided by the analysis of domestic R&D expenditure structure (Table 4). Between 2020 and 2023, total internal R&D expenditures increased by 94%, reaching €345.2 million. However, this expansion was unevenly distributed across sectors. The most pronounced growth occurred in the higher and vocational education sector, where expenditures increased by 361.5%, reflecting intensified state support for university-based research. In contrast, the business sector's share declined sharply, from 41.3% in 2020 to 20.5% in 2023, indicating weakening private-sector engagement. Since 2021, a gradual decline has also been observed in the non-profit sector. From the perspective of funding sources, the share of own funds decreased by nearly 24%, while the contribution of republican and local budgets increased by 22.7%, reinforcing the growing dependence of Kazakhstan's scientific system on public financing.

Table 4. Comparative analysis of the structure and growth rates of domestic R&D expenditures for 2020-2023

Indicators	2020		2021		2022		2023		Growth rate, 2023 - 2020, %
	Million euros	%	Million euros	%	Million euros	%	Million euros	%	
Internal R&D costs, including:	178.0	100.0	218.6	100	243.2	100.0	345.2	100.0	94.0
current	159.2	89.4	193.2	88.4	220.6	90.7	295.0	85.5	85.3
capital	18.8	10.6	25.4	11.6	22.6	9.3	50.2	14.5	167.0
by sector of activity									
Public sector	57.6	32.3	74.2	33.9	76.0	31.3	99.4	28.8	72.6
Higher Professional Education Sector	29.6	16.6	42.4	19.5	75.4	31.0	136.6	39.6	361.5
Business sector	73.6	41.3	76.4	34.9	63.8	26.3	71.0	20.5	–3.5
Non-profit sector	17.2	9.8	25.6	11.7	27.8	11.4	38.2	11.1	122.1
by funding sources									
Own funds	71.0	39.9	73.0	33.4	56.2	23.1	55.2	16.0	–22.3
Funds from the republican and local budgets	92.6	52.0	128.2	58.6	163.8	67.4	258.0	74.7	178.7

Indicators	2020		2021		2022		2023		Growth rate, 2023 - 2020, %
	Million euros	%	Million euros	%	Million euros	%	Million euros	%	
Foreign funds	4.4	2.5	4.2	1.9	5.6	2.3	5.8	1.7	31.8
Other	10.0	5.6	11.2	6.1	17.4	7.2	26.2	7.6	162.0

Source: compiled by the authors according to https://stat.gov.kz/ru/

To examine future trends in business-sector R&D expenditures, the time series was tested for anomalies using Irwin's criterion (Table 5). All observed values fell below the critical threshold at the 95% confidence level, indicating the absence of anomalous observations.

Table 5. Checking for the presence of anomalous observations in a time series

Year	Business-sector R&D expenditure (€ million)	Observed value of Irwin's criterion	Calculation formulas
2020	73.6	-	▪ Observed value of Irwin's criterion: $\lambda_t = \frac{\lvert y_t - y_{t-1} \rvert}{\sigma_y}, \quad t = \overline{2,8}$ ▪ Critical value of Irwin's criterion: $\lambda_{0,05} = 1,5$
2021	76.4	0,597	
2022	63.8	2,685	
2023	71.0	1,534	
2024	73.6	0,213	

Source: compiled by the authors

Subsequent testing using the criterion of ascending and descending series confirmed the presence of a trend component (Table 6). A first-degree polynomial model was therefore estimated using the least squares method: y_t =4195.06−2.04t, where y_t represents business-sector R&D expenditures (million euros). The model indicates a slight downward trend, with an average annual decline of approximately €2.04 million.

Table 6. Checking for a trend

Ascending–descending series criterion for trend detection	$\nu(n) > 1,11$
	$K < [K_0(n)]_{max}$
Calculated values with error probability $0,05 < \alpha < 0,0975$	1< 2
	2 < 5

Source: compiled by the authors

Model adequacy was assessed through residual analysis (Table 7). Despite minor deviations from normality, the residuals exhibit randomness and zero mean, and the average relative approximation error of 4.9% indicates satisfactory predictive accuracy. The model was therefore deemed suitable for forecasting.

Table 7. Model adequacy test

Property being tested	Statistics used		Border	Conclusion
	Name, calculation formula	The resulting value		
Accident	The number of turning points (2) exceeds the critical value (0.111).	2,0	>0,52	Adequate
Normality	RS - criterion: $RS = \frac{e_{\max} - e_{\min}}{S}$	-0,72	2,50-3,31	Inadequate
Zero expected value of residuals	t-Student's t-statistics: $t_{observ.} = \frac{\lvert \bar{e} \rvert}{s}\sqrt{n}$	0	<2,776	Adequate

Source: compiled by the authors

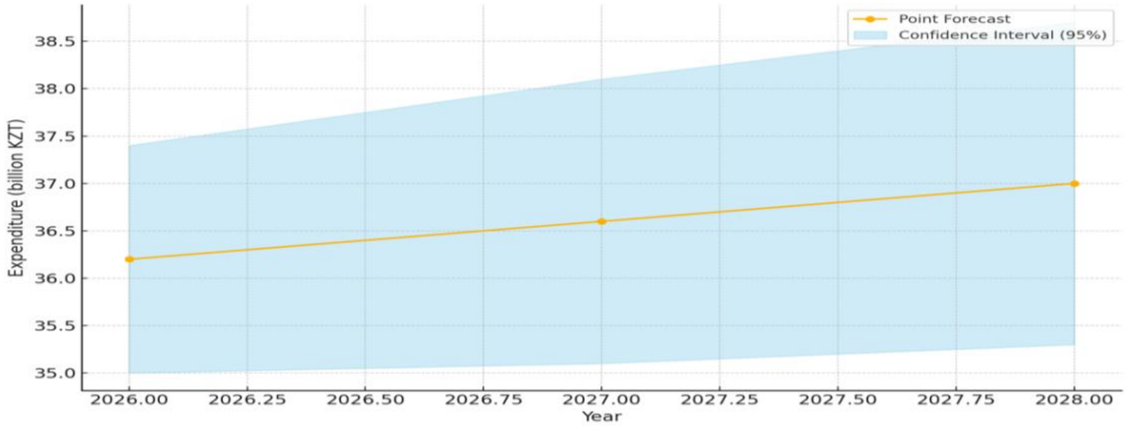
Point and interval forecasts for 2026–2028 are presented in Table 8 and visualized in Figure 3. The results suggest continued stagnation or decline in business-sector R&D expenditures, reinforcing concerns regarding private-sector disengagement from scientific investment.

Table 8. Point and interval forecasts of business-sector R&D expenditures (€ million), 2026–2028

Year	Point Forecast	Interval Forecast, million euros	
		Max	Min
2026	31.01	4.78	0.48
2027	29.99	5.09	–0.72
2028	28.97	5.41	–1.95

Source: compiled by the authors

Figure 3. Forecast of business-sector R&D expenditures, 2026–2028



Source: Compiled by the authors

A comparative perspective is provided by Finland, a country that consistently allocates 2.7–2.9% of GDP to R&D, with 65–70% financed by the private sector. Finland's innovation success is closely linked to strong science–industry integration, outcome-oriented governance, and coordinated policy frameworks, exemplified by institutions such as Business Finland and Aalto University.

Unlike Kazakhstan's rapid expansion of university-based R&D spending, Finland emphasizes commercialization efficiency, technology transfer, and entrepreneurial outcomes. Instruments such as innovation vouchers, proof-of-concept grants, and technology transfer offices contribute to significantly higher returns on academic research investment.

The analysis confirms that sustained growth in R&D funding, particularly through grant and program-targeted mechanisms, strengthens the scientific environment and enhances Kazakhstan's innovation capacity. However, persistent regional inequalities, weak private-sector participation, and limited science–business integration constrain the full realization of scientific potential.

Cluster analysis of regional universities reveals substantial disparities in resource allocation, which undermine the formation of regional centers of scientific growth. Addressing these imbalances requires policies aimed at equalizing access to research infrastructure, stimulating regional scientific activity, and strengthening intersectoral collaboration. Overall, the results demonstrate that scientific potential is a key driver of innovation, economic diversification, and competitiveness. However, translating this potential into sustainable economic outcomes requires not only increased funding, but also institutional reform, private-sector incentives, and outcome-oriented governance aligned with international best practices.

4. Discussion: Private-Sector Incentives and the Efficiency of R&D Financing in Emerging Economies

The results for Kazakhstan highlight a central paradox frequently observed in emerging economies: rapid growth in public R&D funding does not automatically translate into stronger private-sector participation or improved commercialization outcomes. As shown in Table 2 and Figure 1, republican budget allocations to R&D increased substantially between 2020 and 2023. However, this expansion coincided with a pronounced decline in the business sector's share of domestic R&D expenditures, which fell from 41.3% to 20.5% over the same period (Table 4). This divergence underscores a structural imbalance in the national innovation system.

From a theoretical perspective, these findings are consistent with endogenous growth models that emphasize market failures in R&D investment, including high uncertainty, knowledge spillovers, and long payback periods. In the Kazakhstan case, these failures appear insufficiently addressed by existing policy instruments. The forecasted stagnation and gradual decline of business-sector R&D expenditures for 2026–2028 (Table 8; Figure 3) further reinforce the conclusion that increased public funding alone is unlikely to reverse private-sector disengagement.

The discussion therefore shifts from the scale of funding to its composition and incentive structure. While the strong growth of grant and program-targeted funding reflects an active role of the state in shaping scientific priorities, the dominance of budgetary financing suggests a substitution effect rather than a crowding-in of private investment. This interpretation is supported by the growing concentration of R&D expenditures within the higher education sector (Table 4), which, although beneficial for academic capacity building, has not yet generated sufficient spillovers into business-driven innovation.

International experience suggests that under such conditions, the role of the state should evolve from primary financier to risk mitigator and incentive designer. Tax-based instruments, such as R&D tax credits and super deductions, directly reduce the marginal cost of private research and are particularly effective in tax-sensitive corporate environments. Their relevance for Kazakhstan is evident given the weak response of private investment to rising public spending.

Equally important are incentives targeting human capital mobility between academia and industry. The rapid expansion of university-based R&D activity documented in the results section highlights a growing reservoir of scientific talent. However, without complementary measures, such as wage subsidies, reduced social contributions for researchers, or support for corporate research units, this potential remains weakly integrated into the productive sector.

The discussion also emphasizes the role of risk-sharing and demand-side instruments. Matching grants and public–private research consortia are especially effective at early stages of the innovation cycle, when uncertainty is highest. In addition, innovation-oriented public procurement can create guaranteed demand for new technologies, addressing one of the key commercialization barriers identified in the analysis (Figure 2). These mechanisms align scientific output more closely with market needs and reduce the gap between research and application.

Overall, the Kazakhstan case illustrates that the efficiency of scientific potential depends not only on funding growth, but on the alignment of fiscal, institutional, and market incentives. The observed shift toward a budget-dominated R&D financing model risks limiting long-term competitiveness if not accompanied by measures that actively stimulate private-sector engagement. For emerging economies, the central policy challenge is therefore to design incentive frameworks that transform public investment into a catalyst for private innovation rather than a substitute for it.

Conclusion

The findings of this study demonstrate that scientific potential, when strategically mobilized, plays a decisive role in strengthening national competitiveness. Sustained public and private investment in research and development contributes not only to higher levels of scientific output but also to broader innovation performance, reinforcing the central importance of knowledge-based growth in contemporary economic systems.

At the regional level, the results highlight the significance of well-developed research infrastructure and human capital in shaping economic outcomes. Regions with stronger scientific capacity tend to exhibit superior economic performance, underscoring the role of territorially embedded innovation ecosystems in fostering sustainable development.

Despite these positive dynamics, persistent structural barriers to the effective commercialization of research remain evident. Limited interaction between academic institutions and industry continues to constrain the translation of scientific knowledge into economic value. Addressing this gap represents a critical challenge, particularly for emerging and transition economies seeking to maximize the returns on public investment in science. By contrast, targeted investment in research and higher education infrastructure, combined with increased engagement of academic institutions in applied research and collaborative projects, is associated with notable improvements in innovation outcomes. Infrastructure modernization and applied academic participation emerge as key catalysts for technological advancement and innovation system development.

The analysis further underscores the relevance of international experience in shaping effective science and innovation policies. Coordinated public–private co-financing models and integrated innovation governance frameworks, as demonstrated in countries such as Finland, South Korea, and Germany, provide valuable guidance for optimizing the use of research resources. The Finnish case, in particular, illustrates how strategic policy alignment and institutional coordination can generate substantial innovation outcomes even under constrained budgetary conditions.

Overall, the study offers evidence-based insights for science and innovation policy design, emphasizing the need for integrated investment strategies, stronger academia–industry linkages, and adaptive governance mechanisms to support long-term, inclusive economic growth. Scientific potential should therefore be viewed not merely as an academic asset, but as a strategic national resource central to technological progress, socioeconomic resilience, and sustainable development. For emerging and transition economies, adapting international best practices to local institutional contexts, including diversified performance-based funding, robust science–industry collaboration, outcome-oriented innovation governance, and more equitable regional access to research infrastructure, can significantly enhance innovation capacity.

In this context, Kazakhstan represents a relevant case with broader implications for similarly positioned states. Strategic policy interventions, supported by international cooperation and adaptive learning, can accelerate the transformation of scientific potential into a durable competitive advantage. This study contributes to the literature by empirically linking scientific potential, regional innovation infrastructure, and national competitiveness within an endogenous growth framework. While the analysis is constrained by data availability and the relatively short post-reform period, future research may extend this approach through panel data techniques or efficiency-based methods to enhance cross-country comparability. From a policy perspective, the findings suggest that increased public funding for science should be complemented by market-based incentives that stimulate private R&D investment and strengthen science, industry integration.

Credit Authorship Contribution Statement

Yessenbek, Ch. led the conceptualization of the study, designed the methodology, and supervised all stages of data collection and analysis. The author conducted the core empirical analysis, coordinated the research process, and prepared the original draft of the manuscript, taking primary responsibility for the integrity and final approval of the work. Bekbolsynova, A. contributed to data collection, statistical analysis, and visualization, and participated in drafting and revising the manuscript, particularly the empirical sections. Numanova, F. contributed to the literature review, policy analysis, interpretation of results, and critical revision of the manuscript. All authors have read and approved the final version of the manuscript and agree to be accountable for its content.

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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N/A

Data Availability Statement

The data that support the findings of this study are available from the official statistics of the Republic of Kazakhstan (2015–2024) and from publicly accessible government reports on construction, R&D, and environmental indicators. Derived data and analyses generated during this study are available from the corresponding author upon reasonable request.

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