# “Regional innovation efficiency in Kazakhstan: Evidence from stochastic frontier and cluster analysis”


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# REGIONAL INNOVATION EFFICIENCY IN KAZAKHSTAN: EVIDENCE FROM STOCHASTIC FRONTIER AND CLUSTER ANALYSIS

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## Abstract

Innovative and effective territorial development drives the country's economic growth and its ability to compete on the world stage. The purpose of this paper is to quantify the effectiveness of regional innovative development and to use cluster analysis to identify typological groups of regions and pinpoint priority points of innovative growth. The study's statistical database consists of official data from the Bureau of Statistics of Kazakhstan for the period 2003–2024. The study used econometric methods such as panel regression, stochastic, and cluster analysis. The results demonstrate that the innovative development of the regions of Kazakhstan is positively influenced by the human resource factor ($\beta = 1.131$, $p < 0.001$) and socio-economic development ($\beta = 1.894$, $p < 0.001$), and negatively influenced by the level of R&D costs ($\beta = -0.473$, $p = 0.016$). The results of the SFA analysis showed that regions with industrial specialization have the most effective innovative development (Pavlodar TE = 0.764, Kostanay TE = 0.751) in the production of innovative products, and that growth may be driven by investments in fixed assets (SFA ($\beta = 1.565$, $p < 0.001$)). Cluster analysis showed that cluster 1 is characterized by a high level of commercialization, whereas cluster 4 demonstrates a high level of innovation activity; cluster 2 has a high level of knowledge intensity and return on science; cluster 3 has a good technological base. The results showed that a high level of financing does not always lead to breakthrough innovation.

**Keywords** innovation development, regional innovation, human capital, technological efficiency, Kazakhstan

**JEL Classification** C23, O31, R58

## INTRODUCTION

Innovative development is considered as one of the key factors for the long-term competitiveness and sustainability of regional economies. In the context of technological transformations, the ability of regions to effectively use scientific, investment, and human potential is becoming an important condition for economic modernization. In Kazakhstan, issues of innovative development also occupy a significant place in the state's economic policy. Since 2010, the country has been implementing a state program for accelerated industrial and innovative development to stimulate innovation and increase the commercialization of innovative products (Adilet, 2010). In addition, the National Development Plan of the Republic of Kazakhstan until 2029 aims to develop high-tech industries, digitalize the economy, and increase investment activity (Adilet, 2024). Despite the expansion of government support measures, the effectiveness of innovation activities in Kazakhstan remains limited. According to the World Bank (2024), domestic R&D costs amount to about 0.16% of GDP, which is significantly lower than the global average. At the same time, Kazakhstan`s economy remains dependent on raw materials, and the scientific and



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production potential is unevenly distributed across the country. According to the Global Innovation Index (WIPO, n.d.), Kazakhstan ranks 81st among 139 countries, highlighting structural constraints in its national innovation system. This indicates the existing gap between government support and the final innovative result. This issue is significant at the regional level because regions differ in industrial specialization, scientific potential, and infrastructure development.

## 1. LITERATURE REVIEW AND HYPOTHESES

The relationship between innovation and the competitiveness of regional economies has become a central theme of modern economic research. The innovation process is carried out through the effective involvement of human, infrastructural, and financial resources, which can subsequently affect the effectiveness of innovative development. Numerous studies emphasize that human capital, including the quality of education, scientific potential, and research competencies, plays a crucial role in technological development and commercialization of innovations (Mincer, 1981; Pylypenko et al., 2023). Empirical evidence suggests that countries that invest more actively in human capital development tend to demonstrate higher innovation activity and stronger commercialization potential (Wang et al., 2021; Lin et al., 2023). In addition to the role of human capital in the innovation process, another important factor is the state's participation in the supply and promotion of advanced infrastructure and technologies, which will contribute to the growth of the country's innovation potential. Research shows that modernization of infrastructure and equipment will lead to the creation of new product types, which will subsequently not only increase production costs but also enhance the competitiveness of production forces (Lapaev & Moldagulova, 2019; Podra et al., 2020).

However, several studies show that the effectiveness of R&D spending depends not only on the amount of funding but also on the quality of institutional coordination and management mechanisms. In a resource-based economy, high R&D costs can be combined with low commercialization results and low technology adoption (Cassiman & Veugelers, 2006; Schot & Steinmueller, 2018). Empirical evidence from technologically advanced countries, including the United States, Israel, Japan, and the Republic of Korea, confirms that sustainable research and development financing and favorable institutional conditions enhance the effectiveness of innovation systems (Moncada-Paternò-Castello, 2022; Osińska et al., 2022; Bae & Lee, 2020; Oguzturk et al., 2021; Seo & Jung, 2025; Thao & Min Ahn, 2025). Thus, existing research generally confirms the importance of R&D intensity as a key determinant of innovation effectiveness and technological competitiveness. It should also be noted that innovations are closely related to the country's overall socio-economic development. Sustainable socio-economic development and favorable living conditions can stimulate innovation processes (Cheung, 2014; Gürler, 2022; Xie & Khan, 2024). Institutions and the social environment (public administration, infrastructure, and legal framework) create prerequisites for innovation and economic growth (Mukayev et al., 2023). Thus, for the country's innovative development, it is necessary to combine efforts to build human capital and increase investments in fixed assets, especially in infrastructure, technology, innovation, and knowledge-intensive industries.

Another mechanism for accelerating the innovation cycle in the country is to monitor the effectiveness of the region's innovative development. An effective innovation development strategy promotes a more rational use of available resources and increases product competitiveness (Lehmann et al., 2004; Abdelkarim & Zuriqi, 2020; Raithatha & Haldar, 2021; Yucel et al., 2025). Research shows that the effectiveness of innovation activity depends not only on the amount of resources attracted, but also on their rational use. The optimal combination of financial, human, and technological resources enhances the effectiveness of innovation processes and supports commercialization (Abdukadirovna, 2021; Huseynova, 2025). An important role is also played by the interaction of universities, business, and the state, which ensures the exchange

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of knowledge, the development of innovation infrastructure, and the formation of a favorable environment for the creation and implementation of innovations (Nemlioglu & Mallik, 2021; Liao & Zhang, 2022; Susantinah et al., 2023; Iriogbe et al., 2024). Thus, the efficient use of resources is one of the key conditions for successful innovative development and increased economic competitiveness.

However, despite the extensive literature on innovation development, previous studies have mainly focused on the impact of finance, infrastructure, and human capital on innovation, while paying much less attention to the effectiveness of regional innovation development. This issue is especially relevant for resource-based economies, where the concentration of financial resources does not always ensure the effective commercialization of innovations. In Kazakhstan, regional differences in industrial specialization, infrastructure, and scientific potential, as well as uneven funding concentration, can lead to significant variations in the effectiveness of the innovation process across territories.

For resource-based economies such as Kazakhstan, where raw materials predominate over financial resources, effective innovation development is especially important, as dependence on extractive industries can constrain technological diversification and reduce incentives to commercialize innovations.

In this regard, the purpose of this study is to quantify the effectiveness of regional innovative development and to identify typological groups of regions and priority points for innovative growth. Accordingly, the following research hypotheses were put forward:

H1: *Human capital and research staff are significant determinants of innovation output.*

H2: *There are significant differences in the technical efficiency of innovative development across Kazakhstan's regions.*

H3: *The technological frontier of regional innovative development is associated with investment in fixed assets.*

## 2. METHOD

The research methodology comprises econometric panel-data regression analysis, stochastic frontier analysis (SFA) of production boundaries, and cluster analysis to comprehensively assess the effectiveness of innovation processes across regions of Kazakhstan. A special feature of regression analysis is that it allows to identify factors (Jaspen et al., 1968; Sharma et al., 1978; Menard, 1996) that influence the production of innovative products. The use of SFA enables the measurement of resource efficiency and the identification of constraints affecting regional innovation efficiency (Kumbhakar & Lovell, 2000; Firms, 2014; Zhao et al., 2022). The combination of regression and SFA provides an integrated approach. First, the impact of key factors is assessed, and then the effectiveness of development is evaluated, accounting for random fluctuations and structural differences across regions. The study used official statistical data from the Bureau of National Statistics of the Republic of Kazakhstan for the period 2003–2024. The sample covers 20 regions, ensuring national representativeness and the accuracy of the statistical analysis. The selection of regions follows the official administrative division of the Republic of Kazakhstan, which covers all regions and cities of national significance. This approach ensures comparability, avoids selection bias, and enables a comprehensive assessment of regional innovation differences.

The panel dataset nominally covers 20 regions for the period 2003–2024. However, the Abai, Ulytau, and Zhetysu regions were officially established only in 2022. As a result, the panel is unbalanced for these regions. In particular, data on R&D personnel and R&D expenditures (Xstaff, Xmoney) are available starting from 2017, as the Bureau of National Statistics began publishing science and innovation indicators for these territories prior to their official administrative establishment. Gross regional product and GRP per capita are available starting from 2021, while the full set of variables, including fixed asset investment and the volume of innovative products sold (Yrealized), is available only starting from 2022, corresponding to the official creation of these regions. Therefore, observations for 2003–2016 are absent for these territories. After excluding missing values, the


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fixed-effects model was estimated using 344 observations across 20 regions. The calculations and conclusions were carried out in several stages. At the first stage, a regression analysis was performed. The use of panel regression allows for the control of time-invariant regional characteristics, including geographical and structural differences, while focusing on changes in innovation indicators over time. The indicators presented in Table 1 were used for the analysis.

To eliminate the effect of heteroscedasticity and interpret the results in terms of elasticity, all cost indicators are converted to natural logarithms and have the following panel regression model:

$$\begin{aligned} Ln\left(Y\_relized_{it}\right) &= \beta 0 \\ &+\beta 1\ln\left(X\_money_{it}\right)+\beta 2\ln\left(Invest_{it}\right) \\ &+\beta 3\ln\left(X\_staff_{it}\right)+\beta 4\ln\left(GDP\_pc_{it}\right) \\ &+\alpha_{it}+\varepsilon_{it}, \end{aligned} \tag{1}$$

where $i$ – region, $t$ – time period, β1…β4 – elasticity coefficients, $\alpha_{it}$ – individual fixed effects of each region, taking into account their unique, time-invariant characteristics, $\varepsilon_{it}$ – accidental model error.

At the next stage, an efficiency assessment (SFA) was conducted using the obtained data and regression analysis results. While regression analysis estimates the average relationship between variables, SFA estimates the production frontier and measures how efficiently regions transform available resources into innovation output. Mathematically, the stochastic boundary model (in accordance with the Battese and Coelli approach) is written as follows:

$$\ln\left(Y_{it}\right)=f\left(X_{it},\beta\right)+\nu_{it}+\upsilon_{it}, \tag{2}$$

where $f\left(X_{it},\beta\right)$ – production function, $\nu_{it}$ – random noise, $\upsilon_{it}$ – technical inefficiency (loss of output due to inefficient use).

Since the inefficiency component is assumed to be time-invariant, the technical efficiency (TE) index is estimated as a single value for each region over the entire study period rather than for individual years. Consequently, the reported TE scores reflect each region's overall position relative to the estimated innovation frontier based on all available observations in the panel dataset. Based on the stochastic model, a technical efficiency index (TE) was calculated for each region. This index ranges from 0 to 1, with a high value indicating greater efficiency and a low value indicating that regions are using only a small fraction of their available innovation resources. At the third stage, clustering is performed using the K-means method to identify "growth points." This approach enables the identification of qualitative differences in patterns of innovative development, rather than simply ranking regions by volume. This analysis uses several indicators to group regions into clusters (Table 2).

Further, a stability check was performed using stress tests on the models to eliminate uneven values that could distort the results. To identify possible outliers, a comparison was conducted to assess the factors affecting the volume of innovative

**Table 1.** Main variables of econometric analysis

| Variable | Designation | Role in the model | Description and justification | Source |
|---|---|---|---|---|
| The volume of innovative products sold | $Y_{realized}$ | Dependent (Output) | Market realization of innovative products | Bureau of National Statistics (BNS, 2024a) |
| R&D costs | $X_{money}$ | Independent (Input) | R&D financing | Bureau of National Statistics (BNS, 2024b) |
| R&D staff | $X_{staff}$ | Independent (Input) | The role of the human factor in R&D | Bureau of National Statistics (BNS, 2024b) |
| Investment | Invest | Independent (Input) | Investments in fixed assets reflect the level of technological innovation and physical capital | Bureau of National Statistics (BNS, 2024c) |
| GRP per capita | $GDP_{pc}$ | Control | Gross regional product per capita. It is used to monitor the level of economic development of the region | Bureau of National Statistics (BNS, 2024d) |

**Table 2.** Indicators to group regions into clusters

| Coefficient | Calculation formula | Value |
|---|---|---|
| Commercialization rate (*CR*) | $\frac{Volume\ of\ products\ sold}{Volume\ of\ products\ produced} \cdot 100\%$ | It shows which part of the innovation has found a real buyer. This indicator reflects the degree of commercialization of innovation. |
| The level of innovation activity (*IR*) | $\frac{Enterprises\ with\ innovations}{Total\ number\ of\ enterprises} \cdot 100\%$ | It shows the level of innovative activity of enterprises. |
| Knowledge-intensive economy (*RI*) | $\frac{R\ \&\ D\ costs}{GRP} \cdot 100\%$ | It shows how much of the region's income is reinvested in new knowledge. |
| Market returns from R&D (*ES*) | $\frac{Volume\ of\ products\ sold}{R\ \&\ D\ costs}$ | It shows how much real revenue is generated by 1 tenge invested in science. |
| Investment activity (*InvI*) | $\frac{Investments\ in\ fixed\ assets}{GRP} \cdot 100\%$ | It shows the level of intensity of updating the region's material and technical base. |

products produced and sold. In addition, alternative lag specifications have been tested, showing changes over time.

# 3. RESULTS

This study examines the factors determining the effectiveness of regional innovative development in Kazakhstan using panel econometric methods. To determine the optimal panel regression specification, a comparative analysis of fixed-effects (FE) and random-effects (RE) models was conducted. The choice between the models was based on the Hausman test (Hausman, 1978). The Hausman test results ($\chi^2 = 29.84$, $p$-value = 0.0000) indicated that the individual regional effects are correlated with the explanatory variables. Therefore, the random-effects model was rejected in favor of the fixed-effects model. According to the FE model ($R^2$_within = 0.4801), the selected factors explain approximately 48% of the within-region variation in the volume of innovative products.

According to the panel regression with fixed effects (Table 3), there is a strong positive relationship with human capital ($\beta = 1.131$, $p < 0.01$) and the overall level of economic development ($\beta = 1.894$). Both indicators are significant at the 1% level; in particular, a 1% increase in the number of researchers leads to a 1.13% increase in sales of innovative products. In this case, hypothesis 1 is confirmed, which posits that human capital is one of the key determinants of innovative output in Kazakhstan. The results also show a negative relationship between the innovation process and R&D costs ($\beta = -0.473$, $p = 0.016$). In addition to the regression results, stochastic frontier analysis (SFA) was used to assess the effectiveness of regional innovation development. The analysis is based on the Technical Efficiency Index (TE), which ranks regions according to their proximity to the efficiency boundary.

The stochastic frontier model was estimated using the Battese and Coelli (1988) time-invariant specification in Stata 19 (xtfrontier). The frontier function included ln(Invest) and ln(X_money) as determinants of innovation output. The structural parameters of the estimated model are presented in Table 4.

The gamma statistic ($\gamma = 0.737$) indicates that approximately 74% of the total residual variance

**Table 3.** Fixed effects panel regression

| Variables | Coefficient | St.error | t-statistics | P-value |
|---|---|---|---|---|
| Ln $X_{money}$ | –0.473 | 0.195 | –2.43 | 0.016 |
| Ln Invest | 0.074 | 0.344 | 0.22 | 0.829 |
| ln $X_{staff}$ | 1.131 | 0.255 | 5.82 | 0.000 |
| Ln $GDP_{pc}$ | 1.894 | 0.325 | 5.82 | 0.000 |
| Cons | –9.921 | 2.536 | –3.91 | 0.000 |

*Note:* *** p < 0.01 (high significance), ** p < 0.05 (significance at 5% level).


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**Table 4.** Structural parameters of the stochastic frontier model

| Parameter | Estimate | Notes |
|---|---|---|
| Log likelihood | −671.184 | 4 iterations to convergence |
| Wald chi2(2) | 215.65 | Prob > chi2 = 0.0000 |
| sigma2 ($\sigma^2$) | 9.690 | |
| gamma ($\gamma = \sigma^2 u / (\sigma^2 u + \sigma^2 v)$) | 0.737 | 95% CI: 0.146–0.979 |
| sigma_$u^2$ (variance of inefficiency) | 7.145 | |
| sigma_$v^2$ (variance of noise) | 2.545 | |
| Number of observations / groups | 344 / 20 | min = 2, avg = 17.2, max = 22 per group |

is attributable to systematic inefficiency rather than random noise. This result supports the use of a stochastic frontier specification for evaluating regional differences in innovation efficiency. The Wald $\chi^2$ statistic (215.65, $p < 0.001$) confirms the joint significance of the frontier determinants. Based on the estimated model, regions were ranked by Technical Efficiency (TE) score (Table 5). Under the time-invariant specification of the inefficiency term, TE is estimated as a single value for each region over the available observation period, rather than for each year. For the 17 established regions, the estimates reflect performance over 2003–2024, whereas for Abai, Ulytau, and Zhetysu they are based on the shorter period of 2022–2024 due to data availability. Nevertheless, the estimates provide useful information on the relative position of these regions with respect to the innovation frontier.

According to the results, the group with low efficiency of innovative development includes the megacities of Almaty (0.121) and Astana (0.036). The regions with high efficiency are Pavlodar (0.764) and Kostanay (0.751). Atyrau makes the largest contribution to the country's GDP, while the efficiency of innovative development is 0.006 (minimum efficiency). The substantial variation in TE scores across regions confirms H2.

To better understand the factors determining regions' achievement of the efficiency boundary, an analysis of the elasticity of innovative product output with respect to the main types of costs was conducted. Table 6 shows that investments in fixed assets have an elasticity coefficient of 1.565, while R&D expenditures exhibit an elasticity coefficient of 0.046 ($p = 0.744$, statistically insignificant). The results obtained indicate a higher importance of

**Table 5.** Regional technical efficiency scores (Pooled estimates, 2003–2024)

| Efficiency Group | Region | Technical Efficiency Index (TE) | State relative to the frontier |
|---|---|---|---|
| High (TE> 0.7) | Pavlodar | 0.764 | Point of Growth |
| | Kostanay | 0.751 | Point of Growth |
| | North Kazakhstan region | 0.726 | High impact |
| | Karaganda | 0.701 | Stable development |
| Average (0.3 <TE <0.7) | Zhambyl | 0.624 | The average level |
| | City of Shymkent | 0.586 | The average level |
| | Akmola | 0.575 | The average level |
| | West Kazakhstan region | 0.449 | Below average |
| | Ulytau | 0.376 | Emerging potential |
| | Abai | 0.364 | Emerging potential |
| | Zhetysu | 0.302 | Moderate efficiency |
| Low (TE <0.3) | Aktobe | 0.192 | Low impact |
| | East Kazakhstan region | 0.187 | Lack of efficiency |
| | City of Almaty | 0.121 | Critical gap |
| | Almaty region | 0.119 | Low efficiency |
| | Turkestan | 0.091 | Critically low returns |
| | Kyzylorda | 0.059 | Critically low returns |
| | City of Astana | 0.036 | The Outsider |
| | Mangystau | 0.027 | Resource inertia |
| | Atyrau | 0.006 | Minimum efficiency |

**Table 6.** Elasticity of innovation output (SFA)

| Production factor | Elasticity coefficient | Standard error | P-value |
|---|---|---|---|
| Investments in fixed assets (ln Invest) | 1.565 | 0.168 | **0.000*** |
| R&D costs (lnX_money) | 0.046 | 0.142 | 0.744 |

*Note:* *** $p < 0.01$.

**Table 7.** Characteristics of regional innovation development clusters

| Cluster | Regions | CR, % | ES | IR, % | RI, % | Invl, % |
|---|---|---|---|---|---|---|
| Cluster 1 | Shymkent, Kostanay, East Kazakhstan region, Almaty region, Atyrau, North Kazakhstan region, Akmola | 107.14 | **148.03** | 6.87 | 0.04 | 16.02 |
| Cluster 2 | Astana, Almaty city, Abai, West Kazakhstan Region | 98.53 | 4.34 | 12.33 | **0.25** | 13.64 |
| Cluster 3 | Turkestan, Ulytau, Mangystau, Zhambyl | 40.52 | 4.32 | 7.57 | 0.12 | 19.42 |
| Cluster 4 | Aktobe region, Kyzylorda, Karaganda, Zhetysu, Pavlodar | 93.16 | 65.81 | 14.48 | 0.05 | 18.76 |

investments in fixed assets for the growth of innovative output (H3 is confirmed).

Based on the results of the efficiency and elasticity analyses, a cluster analysis was conducted to classify regions by their level of innovation development. According to Table 7, Kazakhstan's regions are divided into 4 clusters. The first cluster unites the regions with the highest R&D market returns (148.03%) at the lowest cost of science (0.04%). These include the cities of Shymkent, Kostanay, East Kazakhstan region, Almaty region, Atyrau, North Kazakhstan region, and Akmola region. The second cluster unites the regions where the main research centers are concentrated, and high innovation activity is observed. These include the

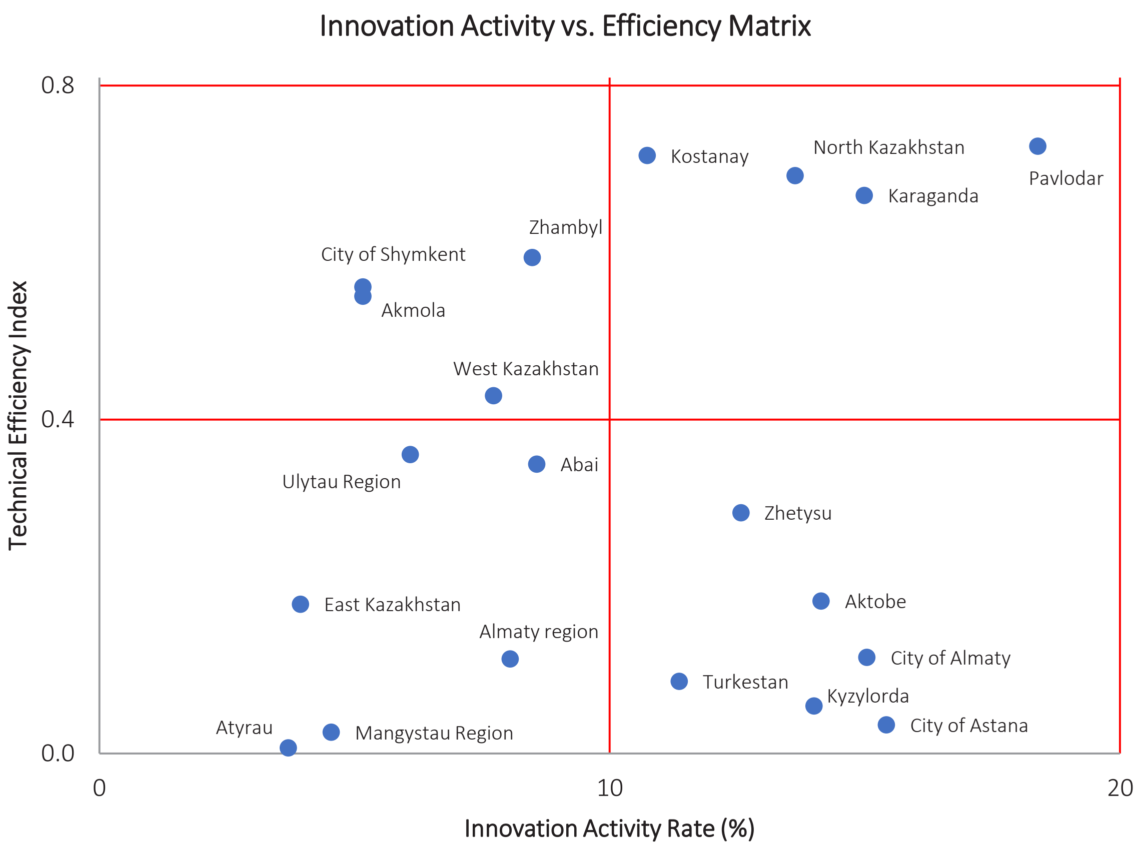


**Figure 1.** Innovation activity vs Efficiency matrix


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cities of Astana, Almaty, and Abai, as well as the West Kazakhstan region. These regions also have a high level of science funding, 0.25%, and critically low returns, 4.34%.

The third cluster unites the regions with the lowest commercialization rate, 40.5%, including Turkestan, Ulytau, Mangystau, and Zhambyl. This cluster unites the regions with the highest level of investment in fixed assets (19.4%) and the lowest profitability (4.32%). The fourth cluster is the most balanced group of regions, comprising Aktobe, Kyzylorda, Karaganda, Zhetysu, and Pavlodar. The highest level of innovation activity (14.5%) is combined with high commercialization (93%) and good returns (65.8%). These are the "growth points" where quantity turns into quality. Figure 1 shows a matrix of clusters that groups regions according to the parameters of innovation activity and efficiency.

To test the sustainability of the results, the largest megacities (Almaty and Astana) were first excluded from the sample, and the investment elasticity coefficient (SFA) remained stable at 1.48–1.52 (compared to 1.565 in the basic model). This confirms that the model of investment and technical development is typical across the whole republic, not just in the capitals. Next, a comparative assessment of the factors influencing the volume of innovative products produced and sold was carried out, the results of which showed that investments significantly affect production volumes (elasticity 0.85, $p < 0.01$), but their impact on product sales is leveled (coefficient 0.074, $p > 0.1$). The key sales factor is personnel, with a coefficient of 1.131 ($p < 0.05$), indicating the priority of human capital in commercialization. Thirdly, alternative delay specifications (t-1, t-2, and t-3) were tested, allowing for possible time delays in the action of the factors. The use of R&D costs with a one-year delay (t-1) did not change the result: the coefficient remained in the negative zone (–0.35...–0.45) at $p = 0.05$. Thus, the results obtained are significant, the model is stable, and the conclusions are correct.

## 4. DISCUSSION

The empirical results of this study indicate a structurally unbalanced regional innovation system in Kazakhstan, where the concentration of financial resources does not guarantee the commercialization of innovations. The results show that the innovative development of Kazakhstan's regions is determined not only by the level of financing, but also by the quality of resource efficiency. These results are consistent with Cubero et al. (2021), who show that financing contributes to the generation of innovative ideas. However, the successful implementation of innovation will require additional conditions that introduce knowledge into the final product. In addition, Slavova et al. (2025) confirm the importance of other factors for converting resources into innovative outcomes. The results of the regression analysis show that human capital ($\beta = 1.131$) plays an important role in economic development and the creation of an innovative product. In addition to the human capital indicator, there is a positive relationship with research staff, indicating that regions with more developed scientific potential are better able to transform scientific research into innovative products. These conclusions are consistent with Kangalakova and Rakhmetova (2021), who link the region's scientific potential to its economic development.

This study found that R&D expenditures show a negative correlation with the dependent variable ($\beta = -0.473$). The results may indicate structural inefficiencies in the allocation and utilization of R&D funding. Namely, the budgetary funds allocated to R&D financing remain at the development stage and, in most cases, do not yield commercial results.

Similar results were reported by Kenzhaliyev et al. (2021), who emphasize the dependence of science on government funding, the formal nature of innovation support, and the lack of communication between science and business, which leads to a low level of commercialization. Thus, this situation may be related to the predominance of fundamental research over applied research and confirms the theoretical position that innovative systems are more related to scientific potential and the availability of qualified human resources than to the volume of investments in research and development. In this context, attention should be paid to the effectiveness of innovative regional development, which reveals gaps in the study using stochastic frontier analysis. The data indicate that regions with the highest concentrations of innovative and financial resources have low technical efficiency, whereas a number of industrial regions exhibit significantly higher efficiency indicators. This indicates that financial, scientific, and infrastructural resources alone are insufficient to ensure effective innovation processes. These findings suggest that the availability of financial, scientific, and infrastructural resources alone does not guarantee higher innovation efficiency. These findings are consistent with Zhang and Huang (2022), who emphasize that both resources and the quality of human capital and the region's socio-institutional environment are crucial for the effectiveness of innovation.

The results show that Pavlodar demonstrates higher innovation efficiency than Atyrau in transforming available resources into innovation output. At the same time, Astana's TE score (0.036) indicates a substantial gap between observed innovation output and the estimated innovation frontier. It was also revealed that technical efficiency in the Atyrau and Mangystau regions is low, which is paradoxical, given that these regions make a significant contribution to the country's GDP. This result suggests that the region's specialization in raw materials may create structural barriers to the spread of innovation and reduce incentives for technological modernization. This is consistent with Isaksen and Karlsen (2013), who highlight that resource-rich regions do not always have an effective innovation system.

Elasticity estimates obtained within the framework of the stochastic frontier model indicate that the availability of industrial infrastructure remains the main condition for increasing the efficiency of innovation in Kazakhstan. When R&D expenditures turned out to be statistically insignificant, this shows a negative effect when testing the sustainability of results with an alternative delay in specifications. It indicates the long-term inefficiency of innovative development and reflects deeper structural constraints of the existing innovation policy. In addition, to deepen the understanding of efficiency, a cluster analysis was conducted. The results show heterogeneity in the distribution of resources that affects the innovation process and its effectiveness. The results show that financing in the largest metropolitan areas does not guarantee successful commercialization, while in regions with lower R&D costs, commercialization yields high returns. From a practical perspective, the study's results emphasize the need to improve the quality of resources in the innovation process. Increased government spending on science is unlikely to significantly increase innovation activity without reforms to both commercialization mechanisms and the relationships among business, universities, and science. In addition, the analysis indicates the need to develop differentiated regional innovation development strategies that account for the region's specific characteristics (industrial, agricultural, petroleum, etc.). Overall, the findings suggest that improving innovation performance requires not only financial support but also more effective utilization of scientific, human, and infrastructural resources across regions.

## CONCLUSION

The purpose of this study is to quantify the effectiveness of regional development and to use cluster analysis to identify typological groups of regions and pinpoint priority areas for innovative growth. Empirical results show that human capital and research staff ($\beta = 1.131$) have a significant positive impact on the effectiveness of innovation activities in the region, whereas R&D expenditures ($\beta = -0.473$) are negatively associated with innovation output. The stochastic analysis showed that higher technical efficiency is observed in regions with a developed industrial structure. In contrast, regions with a high concentration of scientific and financial resources, including large cities, exhibit relatively low efficiency in converting these resources into innovative outcomes. Investments in fixed assets play a more significant role in the development of innovative products than R&D expenditures, which underlines the importance of industrial infrastructure for the innovative development of regions.

Accordingly, Kazakhstan's current innovation policy requires differentiated modernization. For the transition from science to commercialization, it is necessary to reform the national innovation system,


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paying more attention to the results and quality of the innovation process and its resources than to the budget allocation process. Promising areas of further research may include analyzing the dynamic and long-term effects of innovation policy, as well as using enterprise microdata to better understand the factors determining the effectiveness of converting scientific potential into commercially successful innovative products.

## AUTHOR CONTRIBUTIONS

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