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R&D Expenditures and Their Impact on Innovation in the Digital Era: A Kazakhstan Perspective

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ABSTRACT

The article aims to assess the relationship between research and development costs and the level of innovation activity of enterprises in Kazakhstan. The research methodology involves correlation analysis, applying quantitative methods to analyze the collected data from official statistical yearbooks from 2007 to 2022. Correlation analysis with five variables on innovation activity and the impact of research and development costs on that, using Excel and Smart PLS 4 programs were used. According to the results of research, there was a positive impact of R&D expenditure on the level of innovation activity of enterprises mostly, secondly on the ratio of innovative product to gross domestic product, volume of innovative products (goods, services), and showing not so strong correlation on costs of product and process innovations. Digital hubs perform as an ecosystem with a network approach, including organizations in a region to undergo digital transformation in the era of the digital economy and digital technologies. The results of current research might be helpful to academicians and public administration. The originality of the study consists in assessing the impact of R&D expenditure on innovation management in a particular level of innovation activity, the share of innovative products about GDP, costs of product and process innovations, the volume of innovative products (goods, services) to a proper subsequent further contribution. As a result, it is recommended that policy measures focus on enhancing digital infrastructure and supporting R&D investments to ensure sustained innovation performance and economic development.

KEYWORDS: Economic Strategy, Regional Economic Development, Innovation, Innovation Management, Innovation Activity, Digital Hub, Enterprise, Digital Transformation, Collaborative Networks

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Затраты на НИОКР и их влияние на инновационную деятельность в цифровую эпоху: опыт Казахстана

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АННОТАЦИЯ

Цель статьи заключается в оценке взаимосвязи между затратами на научно-исследовательские и опытно-конструкторские работы (НИОКР) и уровнем инновационной активности предприятий в Казахстане. Методология исследования включает корреляционный анализ, применяющий количественные методы для анализа данных, собранных из официальных статистических ежегодников за период с 2007 по 2022 гг. Корреляционный анализ пяти переменных, связанных с инновационной активностью и влиянием затрат на НИОКР, был проведен с использованием программ Excel и Smart PLS 4. Согласно результатам исследования, было установлено положительное влияние расходов на НИОКР на уровень инновационной активности предприятий, а также на долю инновационной продукции в валовом внутреннем продукте, объем инновационной продукции (товары, услуги), при этом наблюдалась менее сильная корреляция с затратами на продуктовые и процессные инновации. Было выявлено, что цифровые хабы выступают в роли экосистем с сетевым подходом, включая организации региона для осуществления цифровой трансформации в условиях цифровой экономики и цифровых технологий. В целом, результаты данного исследования могут быть полезны как для академического сообщества, так и для органов государственного управления. Оригинальность исследования заключается в оценке влияния затрат на НИОКР на управление инновациями, в частности на уровень инновационной активности, долю инновационной продукции в ВВП, затраты на продуктовые и процессные инновации, объем инновационной продукции (товары, услуги), что является основой для последующих исследований. В итоге, рекомендуется сосредоточиться на улучшении цифровой инфраструктуры и поддержке инвестиций в НИОКР для обеспечения устойчивой инновационной деятельности и экономического развития.

КЛЮЧЕВЫЕ СЛОВА: экономическая стратегия, региональное экономическое развитие, инновации, инновационный менеджмент, инновационная деятельность, цифровой центр, предприятие, цифровая трансформация, сети сотрудничества

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INTRODUCTION

In modern conditions, innovation management plays a crucial role in economic development and increasing the competitiveness of enterprises. Research and development (R&D) are becoming the most essential tools for creating new products, services, and technologies, which significantly impact economic growth and technological progress. With increasing investments in R&D, the productivity and innovative activity of enterprises increase, which in turn contributes to solving urgent socio-economic problems.

Today, introducing digital technologies and developing innovation hubs have become the priorities for many countries worldwide. These processes provide new opportunities for economic growth and transformation. In Kazakhstan, despite the presence of significant natural resources, the topic of innovative development and investment in R&D requires further study and in-depth analysis. In this context, it becomes relevant to study the impact of research and development costs on the innovative activities of enterprises, the share of innovative products in GDP, and economic development in general.

However, creating innovations and R&D activities is extremely significant. Research and development is defined as the set of activities (innovative ones) in developing existing services and products or developing new ones. Trajtenberg evaluated the impact of investments in R&D, which further influences economic growth and innovation (Trajtenberg, 1990). Also, studies on the relationship between R&D costs and technology investments showed increased growth and productivity (Romer, 1990); Lichtenberg (1992). Researchers examined the effect of the diversity of teams conducting R&D on the performance of innovations (Garcia et al., 2017). Researchers assessed how strategies for offshoring R&D impact the outputs of innovation performance (Steinberg et al., 2017). Researchers have explored the relationship between external knowledge resources and internal innovation endeavors as tools for solving complex economic circumstances (Zouaghi et al., 2018). According to Usai et al. (2021), the high level of digital technology use impacts organizations' innovation performance. The authors analyzed the role of institutional effect on the innovation performance of enterprises (Yi et al., 2017).

Research on innovation has been conducted by scholars (Hall et al., 2012), where ICT and R&D are considered as factors in the development of innovation, being considered also as inputs for innovation. The study of Wu et al. (2021) confirmed the critical role of ICT in the development of innovation. The innovative activity of enterprises lies in developing new business ideas in an enterprise. Developed countries actively finance R&D and ICT sectors to develop innovations at the state level. The concept of digital hubs is gaining attention in today's digital economy. European Commission realized strategies and projects for developing digital hubs in EU regions. Digital innovation hub was defined as "A DIH is not a one-size-fits-all model or a ready-touse tool for public policy, rather, a framework for enabling a network of actors to discover suitable sets of technologies and services that can spur digital uptake and innovation in a certain region" (Wintjes & Vargas, 2023). One of the main functions of digital hubs is to "test before invest" where the output of R&D activities are tested in testbeds which is the facility of one of the partners' of digital hubs (Sassanelli et al., 2021).

Despite the global focus on R&D and innovation, research on the costs associated with R&D and its impact on innovation in Kazakhstan remains limited. The country's economic development has traditionally relied on its vast natural resources, but in the modern digital economy, reliance solely on raw materials is no longer sustainable. For Kazakhstan to remain competitive on the global stage, it is essential to shift focus toward fostering innovation through increased investments in research and development.

Thus, the article aims to assess the relationship between research and development costs and the level of innovation activity of enterprises in Kazakhstan. The findings of this research will provide valuable insights for policymakers, businesses, and academics interested in promoting innovation and enhancing the competitiveness of Kazakhstan's economy in the digital age.

LITERATURE REVIEW

Romer mentioned that R&D and technological innovation are the basements of economic growth (Romer, 1986). However, enterprises are not enthusiastic about investing in R&D activities (Li, 2017). The study of Wang (2007) confirmed that countries that used effectively the expenditure of R&D show more economic growth. According to Akcali & Sismanoglu (2015), the significance of R&D costs was increased by sustainable growth and international competition. Researchers have found that the organization's size affects the amount of R&D and the propensity to perform R&D work, but the more significant the firm, the lower the R&D productivity (Cohen & Klepper, 1996). The following research-

ers concluded that SMEs play a significant role in innovation (Ferencz & Dugas, 2012). Substantially, technical and financial components, competent specialists play an essential role in creating innovations, which is characteristic of large enterprises. Also, academic research suggests that R&D availability, firm size, and foreign ownership are positively related to innovation performance (Love & Ashcroft, 1999). Other studies suggest a positive rather than negative relationship between innovation and size (Damanpour, 2010). The study of the meta-analytical review found that a mean correlation among 36 from 20 studies showed 0,32 ($p<0,05$) (Damanpour, 1992). Also, studies on size and process and product innovations were conducted, concluding that association with size and process was more positive than with product innovations (Fritsch & Meschede, 2001).

Implementing innovation projects in enterprises would give innovation output (Nursoy, 2012). The positive relationship between R&D and innovation performance was investigated by authors (Bednar & Halaskova, 2018). Also, the strong interdependence between R&D and the level of economic development and innovation performance was examined by authors (Kučera & Fiľa, 2022). The results of this study illustrated a robust positive dependence between the level of innovation performance and R&D costs, as well as a considerable positive dependence between the level of innovation performance on the GDP per capita of analyzed countries. According to the following study, R&D expenditure statistically significantly and positively influenced economic development (Szarowská, 2018).

Earlier research based on the dynamic panel regression model also confirmed the significant influence of R&D costs on economic growth (Szarowská, 2017). Karatheodoros et al. (2019) showed a unidirectional causal relationship between innovation and R&D. Same relationship between innovation and R&D was examined in the study of authors, using time series analysis, also highlighting the positive impact of R&D costs on business (Voutsinas et al., 2018). Recommendations for encouraging various partnerships between R&D, businesses, universities, and the public were proposed by scientists based on the results, which illustrated a co-integration relationship between innovation and R&D costs (Pegkas et al., 2019). The study focused on countries of the European Union and concluded that R&D costs have significant and positive effects on innovation (European Commission, 2019).

Policy orientations toward private-public cooperation are increasingly receiving empirical support from research (Azagra-Caro & Consoli, 2014; Belluci & Pennacchio, 2015). Growth in R&D activities and increased R&D employees positively affect innovation. R&D knowledge also affects the level of innovation. The level of innovation can be increased by utilizing the stock of knowledge from other countries (Porter & Stern, 2000). The long-term number of patent applications to increase R&D expenditure is estimated to be 1.5 on average. Previous studies (Jaffe, 1986) found that an increase in a single company's R&D expenditure by 10 percent will increase innovation by 20 percent.

The countries where technological research is at the center of R&D activities reveal more efforts. Innovations, new processes, and new production methods are outputs of research and development activities. To make those innovations work, they must be effectively used. The authors conducted research on the R&D costs influencing economic growth with an accent on technological innovation, and it was identified that there is a Granger causality between economic growth and R&D, but it is not proven if R&D costs impact economic growth (Öztürk & Oransay, 2017). The activity of R&D is considered to be the use of the available stock of specific, original, technical, and scientific information and the role of human capital to create or improve existing products, processes, and services in order to provide them to the market, responding to the needs of the economy, using necessary information (Pessoa, 2010; Geribadze, 2010).

According to numerous studies, the positive effect of R&D expenditure on innovation has been identified, following that R&D has become an essential factor in sustainable economic development growth and competitiveness (Peng, 2010). Applied research, primary research, and experimental development are part of R&D. Basic research aims to obtain new knowledge in the form of experimental and theoretical work. The basis of applied research is to focus on solving practical problems. Experimental development aims to operate systematically based on practical and fundamental research. Experimental development aims to produce new services, products, production methods, and systems and improve existing developments (OECD, 2015).

Thus, Coe and Helpman (1995) concluded that an increase in R&D leads to an increase in innovation. Thus, an increase in innovation leads to an increase in productivity. As a consequence of R&D activities, new technologies increase production efficiency and solve social problems. Countries that invest more in R&D and long-term R&D activities get the desired results before others and become technology-producing countries. After R&D, the following indicator of a country's technological ca-

pacity is its number of patents. R&D expenditure, on the other hand, is the initial input in the field of technological innovation, where the outcome is technological innovation. Thus, the scholar Becker found a strong relationship between R&D and the number of patents (Becker, 2014).

R&D activities are mainly developed in industrialised countries. ICTs are the primary driver of development in the economic structures of these countries. ICT is driving change in the political and economic arenas, bringing together the world's values on cultural and social grounds (Bor et al., 2012). The role of innovation and R&D is becoming tangible in developing countries. The role of public administration plays a significant role in stimulating projects and strategies for the development of innovation management, start-ups, collaborations, and the formation of digital hubs as tools for digital transformation and the use of digital technologies by organizations in the region for further development of the economics of countries. According to Fagerberg's study (2002), R&D and technological innovation have a positive effect. Digital hubs are instruments of digitalization, acting as one-stop shops that support local organisations in their digital transformation. Digital hubs have their service portfolio with services listed. "Test before invest", searching for investors, funds, technological assessment, and training are the most common functions of digital hubs (Sarraipa et al., 2023).

Numerous studies have explored various aspects of R&D expenditure, including its effect on innovation, its role in driving economic growth, and how the size of organizations influences R&D activities. Research has also focused on the relationship between R&D spending and innovation outcomes, such as the number of patents filed. However, there is limited investigation into the impact of R&D costs on specific variables like the volume of innovative products, particularly in product and process innovation costs. This study seeks to address this gap and test the following hypotheses:

H1: R&D costs influence the level of innovation activity of enterprises.

H2: R&D costs influence the share of innovative products concerning GDP.

H3: R&D costs influence the costs of product and process innovations.

H4: R&D costs influence the volume of innovative products (goods, services).

RESEARCH METHODS

Various research methods have analyzed the relationship between R&D investments and innovation outcomes. Wang (2007) applied a stochastic frontier analysis with a translog specification to data from 30 countries, using R&D capital stock and manpower as inputs and patents and academic publications as outputs. Bednar and Halaskova (2018) conducted an empirical analysis utilizing panel data methods. In another study, correlation and regression analyses were used to examine the relationship between research and development, innovation performance, and economic development (Kučera & Fil'a, 2022). Szarowská (2018) employed panel regression methodology and dynamic panel analysis in her research, while another study used a range of panel data techniques to analyze R&D data and patent outputs. Karatheodoros et al. (2019) investigated the impact of R&D expenditure on innovation in Greek regions using panel data analysis. Finally, Öztürk and Oransay (2017) implemented panel VAS analysis in their research.

The study used quantitative research methods, such as correlation analysis. The Smart PLS program calculates the correlation. Figure 1 illustrates a normal distribution histogram.

Correlation analysis is applied in the research, the formula of which is presented below (1):

$$r_{xy} = \frac{\Sigma(x_i - x_{medium})(y_i - y_{medium})}{\sqrt{\Sigma(x_i - x_{medium})^2 * \Sigma(y_i - y_{medium})^2}} \quad (1)$$

where: r_{xy} - is Pearson correlation coefficient,
x_i - is the i-th element of the selection x,
y_i - is the i-th element of the selection y,
x_{medium}, y_{medium} - are the i-ths elements of the selection x and y.

The following variables were chosen for the current research: y, x_1 - x_4

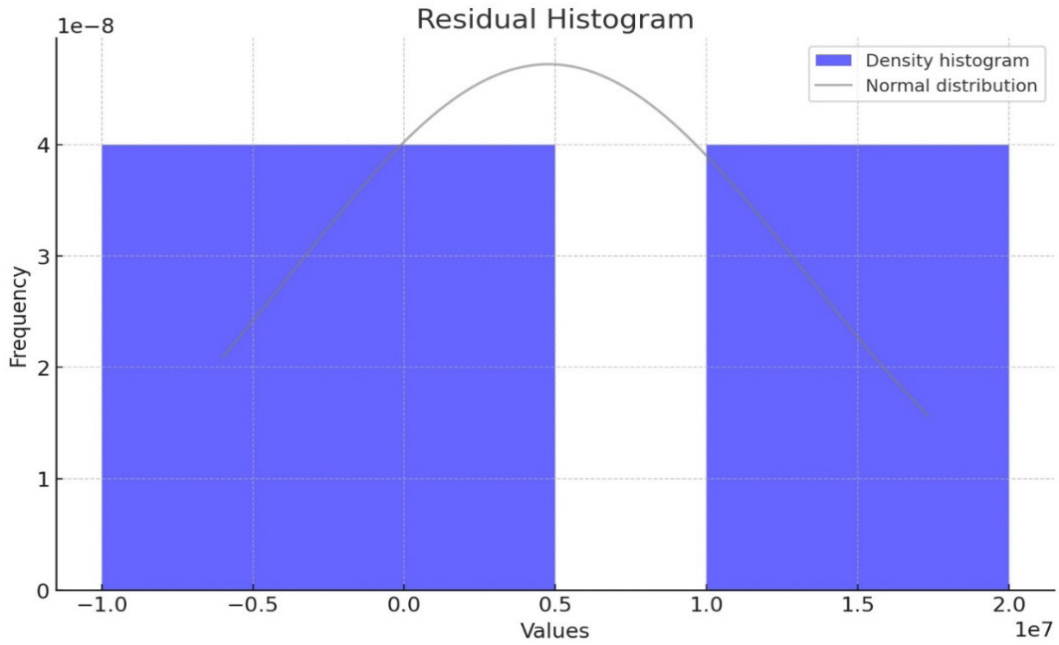

Figure 1. Normal Distribution Histogram

Correlation analysis is applied in the research, the formula of which is presented below (1):

Table 1 below presents comprehensive data collected from the official statistical yearbooks of the Bureau of National Statistics of the Republic of Kazakhstan, spanning the years 2007 to 2022.

Table 1. Description of the study sample

Indicator	Variable	Unit of measurement	Period
Y	R&D costs	Million tenge	2007-2022
X1	Level of innovation activity of enterprises	%	2007-2022
X2	Share of innovative products about GDP	%	2007-2022
X3	Costs of product and process innovations	Million tenge	2007-2022
X4	Volume of innovative products (goods, services)	Million tenge	2007-2022

Source: organized by authors based on the collected data

The study sample includes a range of indicators related to research and development (R&D) and innovation activities within enterprises over a specific period. The primary dependent variable, Y, measures R&D costs in millions of tenge (KZT) from 2007 to 2022. This variable captures the financial commitment enterprises have made towards fostering innovation.

The independent variables (X1 to X4) provide a broader context regarding the innovation landscape:

X1 indicates the level of innovation activity of enterprises, expressed as a percentage, reflecting how engaged companies are in innovative practices over the same period.

X2 measures the share of innovative products in relation to the overall GDP, also in percentage terms, highlighting innovation's contribution to the economy.

X3 focuses on the costs associated with product and process innovations, again denoted in millions of tenge (KZT), allowing for comparing financial investments specific to innovative developments.

X4 captures the volume of innovative products, including goods and services, measured in millions of tenge (KZT), illustrating innovation initiatives' output and market presence.

This framework provides a comprehensive view of the relationship between R&D investments and innovation metrics, enabling a detailed analysis of trends and impacts over fourteen years.

RESULTS

To assess the influence of R&D costs on the innovation activity of enterprises, the following independent and dependent variables were analyzed. As an independent variable, R&D costs were chosen, while dependent variables were the level of innovation activity of enterprises, share of innovative products in relation to GDP, costs of product and process innovations, and volume of innovative products. As the level of innovation activity affects finally the release of innovations and patents, it leads to the growth of competitiveness at the world level.

Table 2 shows the costs of R&D, the level of innovation activity, and the share of innovative products in GDP.

Table 2. The costs of R&D, level of innovation activity and share of innovative products in relation to GDP.

Year	R&D costs	Level of innovation activity	Share of innovative products in relation to GDP
2007	26835,50	4,80	1,19
2008	34761,60	4,00	0,69
2009	38988,74	4,00	0,49
2010	33466,82	4,30	0,65
2011	43351,60	5,70	0,84
2012	51253,10	5,70	1,22
2013	61672,70	8,00	1,61
2014	66347,60	8,10	1,46
2015	69302,90	8,10	0,92
2016	66600,10	9,30	0,95
2017	68884,21	9,60	1,55
2018	72224,60	10,60	1,72
2019	82333,10	11,30	1,60
2020	89028,70	11,50	2,43
2021	109332,70	10,50	1,71
2022	121560,1	11	1,81

Note: organized by authors based on the collected data

According to data, R&D expenditures steadily increased from 2007, starting at 26835.50 million tenge. However, in 2010, there was a slight decline to 33466.82 million tenge, followed by consistent growth until 2015. By 2016, expenditures decreased to 66600.10 million tenge, having reached 69302.90 million tenge in the previous year. Between 2017 and 2021, R&D expenditures significantly increased, nearly tripling, and reached 109332.70 million tenge in 2021, with a further moderate rise to 121560.10 million tenge in 2022.

The costs associated with product and process innovations fluctuated over the analyzed period. In 2007, these costs amounted to 83523.40 million tenge, rising to 785705.00 million tenge in 2021, representing a threefold increase. In 2022, innovation costs further surged to 1,132,848 million tenge. The volume of innovative products showed some volatility. In 2007, the volume was recorded at 152500.60 million tenge but dropped to 111531.10 million tenge in 2008, then further declined to 82597.40 million tenge in 2009. However, from 2010 onward, the volume of innovative products and services nearly doubled, continuing to rise until 2014, when it reached 580386.00 million tenge. In 2015, this figure halved to 377196.70 million tenge. A sharp fourfold increase occurred in 2016, and the upward trend continued until 2020. In 2021, the volume decreased significantly to 1438708.50 million tenge, but by 2022, it experienced a dramatic fourfold increase.

Table 3 presents the percentage of innovation activity levels among enterprises and the share of innovative products relative to GDP, highlighting the variations over the study period.

Table 3. The number of product and process innovations costs and volume of innovative products (goods, services).

Year	Costs of product and process innovations	The volume of innovative products (goods, services)
2007	83523,40	152500,60
2008	113460,10	111531,10
2009	61050,90	82597,40
2010	235501,70	142166,80
2011	194990,90	235962,70
2012	325639,30	379005,60
2013	431993,80	578263,10
2014	434602,50	580386,00
2015	655361,00	377196,70
2016	1528645,90	445775,70
2017	899681,85	844734,90
2018	856449,50	1064067,40
2019	535918,10	1113566,50
2020	777173,51	1715500,10
2021	785705,00	1438708,50
2022	1132848	1879123,1

Note: compiled by authors

The percentage of innovation activity among enterprises was 4.8% in 2007, but it declined to 4.0% during 2008-2009. In 2011-2012, the level increased to 5.7%, and by 2013, it had risen significantly to 8.1%. From 2013 to 2020, the innovation activity percentage steadily grew, reaching a peak of 11.5% before dropping slightly to 10.5% in 2021. By 2022, it experienced a slight recovery, increasing to 11%. The share of innovative products relative to GDP fluctuated over the analyzed period, with the lowest point recorded in 2009 at 0.49% and the highest in 2020 at 2.43%. These variations reflect the dynamic nature of innovation performance in Kazakhstan from 2007 to 2022.

CORRELATION ANALYSIS

Before conducting correlation analysis, a descriptive analysis of the indicators is carried out. Descriptive statistics is used for the summary of data, which is used to define the relationship between variables. Mean means the arithmetic average of values divided by the total general number of observations (Yellapu, 2018). Descriptive statistics are used to reduce the meaning of a sample to measures that provide insight into the distribution and sample, and mathematical meaning tools are used. Descriptive statistics include median, mean, mode, variance, skewness, kurtosis, and standard deviation.

Table 4 shows descriptive statistics of the current study.

Table 4. Descriptive Statistics

Name	Mean	Median	Observed min	Observed max	Standard deviation	Excess kurtosis	Skewness	Cramer-von Mises P-value
Y	52751861.176	663476	109332.000	887406195.000	208663740.544	17.000	4.123	0.000
X1	63.875	81	4.000	115.000	39.394	-1.376	-0.340	0.167
X2	4340916.294	122	16.000	73793637.000	17363180.177	17.000	4.123	0.000
X3	45808985.412	3256393	610509.000	711392524.000	166441074.107	16.978	4.119	0.000
X4	11710828.765	4457757	580386.000	92896701.000	21081654.976	14.121	3.639	0.000

Note: compiled by authors

The lowest mean is given to the variable X1, which is the share of innovative products in relation to GDP, compared with the highest mean, given to the variable Y – the costs of product and process innovations. The middle value in the dataset distribution is the median. The highest median of the variables is seen as a dependent one, which is Y – R&D costs, indicating 44577570,000. The lowest median is given to X1, like a mean, illustrating 122,000. The standard deviation has been measured by the spread of indicators for normal distribution. Distributed data without skewness shows a normal distribution. The standard deviation shows whether the data is away from the center of the distribution. The Cramer V coefficient assesses the strength of the relationship between two nominal variables.

The indicator can range from 0 to 1. No relationship between the two variables indicates a value of 0, while an excellent relationship is indicated by 1. Referring to the data above, only variable X1 indicates 0,167, while others show 0. The relationship between variable X1 and the two variables is weak. The peaks of the distribution are estimated by excess kurtosis, while the degree of symmetry is estimated by skewness. Skewness parameters in normal distribution show, from -1 to +1, are evaluated as excellent, and parameters from -2 to +2 are considered acceptable. From the table above, three of the variables indicate numbers higher than 1 and 2, except X1 – 0.340. A negative value of the excess characterises a flat distribution. Scores with -1 indicate a flat distribution, and X1 scores are -1.376. When the kurtosis and skewness are close to zero, the indicators are said to be normally distributed (George & Mallery, 2019; Hair et al., 2022).

Table 5 illustrates the correlation matrix, where the relationship between dependent and independent variables is seen.

Table 5. Correlation matrix

Indicator	Y	X1	X2	X3	X4
Y	1				
X1	0,887407	1			
X2	0,737937	0,834866	1		
X3	0,711394	0,777251	0,468457	1	
X4	0,928967	0,882645	0,879338	0,609792	1

Note: compiled by authors

According to the correlation matrix, it can be visualised that there is a strong direct relationship between the level of innovation activity of enterprises and R&D expenditure, indicating 0,887407. The following direct solid relationship is seen between the share of innovative products in relation to GDP and R&D costs, showing the number 0,834866. A slightly below-average correlation is seen in the X3 column, showing 0,468457 between R&D expenditure and costs of product and process innovations. The average relationship with R&D costs has the following variable: the volume of innovative products (goods, services), illustrating 0,609792 in the correlation matrix.

Testing the hypothesises following results were conceived:

H1: R&D costs influence the level of innovation activity of enterprises – proven and accepted.

H2: R&D costs influence the share of innovative products in relation to GDP – proven and accepted.

H3: R&D costs influence the costs of product and process innovations – proven and accepted.

H4: R&D costs influence the volume of innovative products (goods, services) – proven and accepted.

DISCUSSION

Today's R&D is critical in creating innovations in a competitive world. The results confirmed that all hypotheses were valid, demonstrating a significant correlation between R&D expenditures and innovation outcomes. Specifically, R&D costs were found to substantially influence both the level of innovation activity within enterprises and the share of innovative products relative to GDP. Moreover, a moderate but notable impact of R&D spending was observed on the costs associated with product and process innovations and the volume of innovative products and services.

This study reaffirms the critical role that R&D plays in driving innovation and further highlights the importance of digital innovation hubs as key facilitators in the R&D and innovation processes. Digital innovation hubs are structured as ecosystems where

various organizations—such as businesses, research institutions, and governmental bodies—collaborate as stakeholders, sharing resources and knowledge to foster innovation (Ujwary-Gil & Florek-Paszkowska, 2022). These hubs leverage a network approach, providing enterprises access to the latest technologies and enabling them to test and refine innovations cost-effectively. The "Test before Invest" approach, a core function of these hubs, helps organizations mitigate the risks associated with innovation by allowing them to experiment with new ideas and technologies before committing significant resources (Ujwary-Gil & Godlewska-Dzioboń, 2022).

The results of this study suggest that digital hubs play a pivotal role in reducing the costs associated with R&D and enhancing the overall efficiency of innovation processes. By facilitating collaboration and resource sharing, digital hubs allow enterprises to accelerate the development and commercialization of innovative products and services. This is particularly important for smaller firms that may lack the financial resources to invest heavily in R&D. As other studies have shown, the size of an organization can influence its innovation capabilities, with smaller firms often benefiting from external partnerships to enhance their innovation output (Bruothová et al., 2014; McNulty, 1974; Chandy & Tellis, 2000).

Given the demonstrated importance of R&D and digital hubs in fostering innovation, policymakers must consider strategies that promote the formation and development of such hubs as part of broader efforts toward digital transformation, public and private sector collaboration can be leveraged to support the growth of digital innovation hubs, particularly in regions where innovation activities are currently underdeveloped. In doing so, regions can create environments that are conducive to innovation, thereby driving economic growth and enhancing competitiveness on both a national and global scale.

The findings of this study underscore the need for continued investment in R&D and the expansion of digital innovation ecosystems. As digital transformation reshapes industries, the ability to innovate rapidly and effectively will become increasingly crucial. Policymakers should prioritize the creation of frameworks that support R&D investments and facilitate collaboration between businesses, research institutions, and government entities. In particular, policies that foster the growth of digital hubs can play a crucial role in enabling regions to attract and retain innovative enterprises, ultimately driving long-term economic development.

CONCLUSION

Today, a global trend around the world is the concept of Industry 4.0, the central aspect of which is the digitalization, digital transformation, implementation, and application of digital technology in all spheres of life of the population around the world. The aim of the study was achieved by testing hypotheses, all of which have been proven and accepted. R&D has an impact on enterprises' innovation activities. This means it would suit policymakers and public and private administrations to allocate funds and investments to R&D activities within a digital hub. In a competitive world, it is critical not to delay innovations. The beginning process of innovation is a research and development activity.

Research and development organisations are partners and stakeholders in the ecosystem of a hub. The range of services of each digital hub differs depending on the use of a particular digital technology or two or more digital technologies. The management of digital hubs focuses on one sector of the economy, for example, education, trade, transport and transportation, air transport, the agricultural sector, and others. From 1990 to 1999, the development of essential infrastructure financing by states, then the development of software such as Microsoft Office and others, concluding this period with the emergence of the Internet and the transfer of technology. From 2000 to 2010, international meetings were held on developing digital cooperation, and private and public funding was discussed in the form of investment in specific projects to develop the Internet.

The mobile Internet, e-commerce, technology development such as phones, digital innovation, and others are emerging. The development of social networks, email, Vkontakte, and Facebook is from 2011 to 2017; also in this period is the creation and development of artificial intelligence, additive technologies, venture capital, broad investment in digital technology, and projects to develop digitalization, the formation of digital hubs, digital infrastructure. Then, in 2018, virtual transformation, robotics, 5G, the sharing economy, and the fourth industrial revolution were developed.

Foreign experience forming digital hubs shows the formation of the first digital hubs in European countries. To date, the European Commission is implementing digitalization programs Horizon and various digital projects to introduce digital technology (European Commission, 2020). The scientific community of foreign countries actively publishes articles on the development and analysis of existing and functioning digital hubs in

their regions. Basically, foreign experience in forming digital hubs considers the development of robotics, artificial intelligence, and cybersecurity to be the leading digital technologies contributing to the rapid pace of digitalization. In Europe, the adoption of digital technology is so advanced that using additive technology in the form of 3D printing, homes that have let their first occupants in are being created there. Also, digital technology, such as 3D printing, is used in almost all areas, ranging from medicine (making teeth in dentistry, parts) to construction (3D houses, apartments).

The results of this study highlight the need for continued investment in research and development and the expansion of digital innovation ecosystems. As digital transformation changes industries, the ability to innovate quickly and efficiently will become increasingly important. Policymakers should prioritize creating mechanisms that support investment in R&D. Future research should continue to explore the dynamics of digital centers and their long-term impact on the effectiveness of innovation activities at the regional and national levels. By integrating digital hubs into broader economic strategies, regions can take full advantage of the potential of R&D investments to promote sustainable innovation and growth.

AUTHORS CONTRIBUTION

Conceptualization and theory: GS; research design: GS and PK; data collection: NZ and AK; analysis and interpretation: GS, PK, NZ and AK; writing draft preparation: GS, PK, NZ and AK; super-vision: NZ and AK; correction of article: GS, PK, NZ and AK; proofread and final approval of article: GS, PK, NZ and AK. All authors have read and agreed to the published version of the manuscript.

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