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DIGITALIZATION OF SCIENCE AS A TOOL FOR INCREASING THE COMPETITIVENESS OF THE ECONOMY OF THE REPUBLIC OF KAZAKHSTAN

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In modern conditions of global competition and rapid technological development, the digitalization of science is becoming particularly important as a factor in increasing economic competitiveness. The purpose of this study is to determine and quantify the impact of the digitalization of the scientific sphere on the growth of the digital competitiveness of the economy of the Republic of Kazakhstan. The relevance of the topic is due to the need for an accelerated transition to a knowledge economy, where science and technology are the main sources of added value growth, the development of high-tech industries and investment attraction. Kazakhstan, despite the existence of digital development and scientific modernization strategies, faces a number of limitations: fragmented digital infrastructure, weak integration of science and business, insufficient level of digital competencies among scientific personnel. In the course of the study, a comparative analysis of the experience of the Republic of Korea was carried out, econometric modeling methods were applied, and an integral index of the digitalization of science was developed. The model revealed a stable positive relationship between the level of digitalization of scientific infrastructure and the country' s position in the global ranking of digital competitiveness. It has been established that even with a moderate increase in digitalization, it is possible to significantly strengthen the innovation potential and increase the efficiency of research and development (R&D). The results confirm the need to implement a holistic government policy on the digital transformation of the scientific field, including process automation, the development of digital platforms, cooperation with business, and strengthening the digital skills of researchers. The findings can serve as a basis for the formation of strategies for scientific, technological and economic development of Kazakhstan in the context of global digital trends.

Keywords: digitalization, infrastructure, science, economics, innovation, investment, artificial intelligence.

ҒЫЛЫМДЫ ЦИФРЛАНДЫРУ ҚАЗАҚСТАН РЕСПУБЛИКАСЫНЫҢ ЭКОНОМИКАСЫНЫҢ БӘСЕКЕГЕ ҚАБІЛЕТТІЛІГІН АРТТЫРУ ҚҰРАЛЫ РЕТІНДЕ

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Әлемдік бәсекелестік пен жедел дамып келе жатқан технологиялық дамудың қазіргі жағдайында ғылым саласын цифрландырулар экономиканың бәсекеге қабілеттілігін арттыру факторы ретінде маңызды болып табылады. Зерттеудің мақсаты ғылым салаларын цифрландырудың Қазақстан экономикасындағы цифрлық бәсекелестікке қабілеттілігінің артуына әсерлерін анықтау және сандық негіздеу болып табылады. Тақырыптың өзектілігі білім экономикасына жедел көшу қажеттілігімен байланысты, мұнда ғылым мен технология қосылған құнның өсуінің, жоғары технологиялық салалардың дамуының және инвестицияларды тартудың негізгі көзі болып табылады. Қазақстан цифрлық даму және ғылыми жаңғырту стратегияларының болуына қарамастан бірқатар шектеулерге тап болады: цифрлық инфрақұрылымның бөлшектенуі, ғылым мен бизнестің әлсіз интеграциясы, ғылыми кадрларда цифрлық құзыреттіліктің жеткіліксіз деңгейі. Зерттеу барысында Корея Республикасының тәжірибесіне салыстырмалы талдау жүргізілді, эконометрикалық модельдеу әдістері қолданылды, ғылымды цифрландырудың интегралды индексі әзірленді.

Модель ғылыми инфрақұрылымды цифрландыру деңгейі мен цифрлық бәсекеге қабілеттіліктің жаһандық рейтингіндегі елдің позициясы арасындағы тұрақты оң байланысты анықтауға мүмкіндік берді. Цифрландырудың қалыпты өсуімен де инновациялық әлеуетті едәуір күшейтуге және ғылыми-зерттеу және тәжірибелік-конструкторлық жұмыстардың (ҒЗТКЖ) тиімділігін арттыруға болатындығы анықталды. Нәтижелер процестерді автоматтандыруды, цифрлық платформаларды дамытуды, бизнеспен кооперацияны және зерттеушілердің цифрлық дағдыларын нығайтуды қоса алғанда, ғылыми саланы цифрлық трансформациялау бойынша тұтас мемлекеттік саясатты іске асыру қажеттігін растайды. Алынған тұжырымдар жаһандық цифрлық трендтер контекстінде Қазақстанның ғылыми-технологиялық және экономикалық даму стратегияларын қалыптастыру үшін негіз бола алады.

Түйін сөздер: цифрландыру, инфрақұрылым, ғылым, экономика, инновация, инвестиция, жасанды интеллект.

ЦИФРОВИЗАЦИЯ НАУКИ КАК ИНСТРУМЕНТ ПОВЫШЕНИЯ КОНКУРЕНТОСПОСОБНОСТИ ЭКОНОМИКИ РЕСПУБЛИКИ КАЗАХСТАН

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В современных условиях глобальной конкуренции и стремительно развивающегося технологического развития цифровизация науки является важным фактором повышения конкурентоспособности экономики. Цель исследования – выявить и количественно обосновать влияние цифровизации науки на повышение цифровой конкурентоспособности экономики Казахстана. Актуальность темы связана с необходимостью ускоренного перехода к экономике знаний, где наука и технологии являются основными источниками роста добавленной стоимости, развития высокотехнологичных производств и привлечения инвестиций. Несмотря на наличие стратегий цифрового развития и научной модернизации, Казахстан сталкивается с рядом ограничений: фрагментированность цифровой инфраструктуры, слабая интеграция науки и бизнеса, недостаточный уровень цифровых компетенций научных кадров. В ходе исследования проведен сравнительный анализ опыта Республики Корея, использованы методы эконометрического моделирования и разработан интегральный индекс цифровизации науки. Модель позволила выявить устойчивую положительную связь между уровнем цифровизации научной инфраструктуры и позицией страны в глобальном рейтинге цифровой конкурентоспособности. Установлено, что даже при умеренном росте цифровизации возможно существенное усиление инновационного потенциала и повышение эффективности научно-исследовательских и опытно-конструкторских работ (НИОКР). Результаты подтверждают необходимость реализации комплексной государственной политики по цифровой трансформации научной сферы, включая автоматизацию процессов, развитие цифровых платформ, сотрудничество с бизнесом и усиление цифровых навыков исследователей. Полученные выводы могут служить основой для формирования стратегий научно-технологического и экономического развития Казахстана в контексте глобальных цифровых трендов.

Ключевые слова: цифровизация, инфраструктура, наука, экономика, инновация, инвестиция, искусственный интеллект.

Introduction. The rationale for the research topic is related to the increasing role of science as a key resource for sustainable development and competitiveness of the economy in the context of the transition to the digital economy and the knowledge economy. Modern scientific systems require a revision of traditional approaches to the organization of research, financing, technology

transfer and interaction with the industrial sector. The digitalization of science is becoming not just a technological modernization, but a fundamentally new paradigm of scientific activity, involving openness, interconnectedness, automation, analytical traceability and rapid commercialization of results.

The relevance of the topic is determined by both internal and external factors. First, digital transformation is becoming a priority of Kazakhstan' s state policy («Digital Kazakhstan», «Science, Technology and Innovation - 2023-2027») [1]. Secondly, competition for scientific personnel, patents and innovations is intensifying in the international arena, where the digital maturity of the scientific sphere provides countries with leading positions. Despite the steps taken in Kazakhstan, the scientific system remains fragmented by digital initiatives, weak integration with business, and limited access to global data and digital ecosystems.

The object of the research is the scientific system of Kazakhstan in the context of digital transformation. The subject of the study is the impact of the digitalization of science on the competitiveness of the economy.

The aim is to quantify and reveal the mechanisms of the impact of the digitalization of science on macroeconomic and institutional indicators of competitiveness.

Research objectives:

- analyze the current level of digitalization of science in Kazakhstan;

- Conduct a comparative analysis with the Republic of Korea;

- to develop an integral index of digitalization of science;

- build a model of the link between digitalization and the competitiveness of the economy;

- Develop practical policy recommendations.

The hypothesis of the study is that the systemic digitalization of scientific infrastructure has a significant positive impact on the growth of digital competitiveness and innovation potential of the country.

Research methods: econometric analysis, factor analysis, cross-country comparison, expert assessment, index construction. The novelty of the work is to build a quantitative model of the relationship between the digitalization of science and the macroeconomic index of digital competitiveness, as well as to identify barriers and directions of digital transformation of science in Kazakhstan [2].

The digitalization of the scientific sphere currently acts not only as a tool for modernizing the research infrastructure, but also as an important factor in the formation of sustainable competitive advantages of the national economy. The transition to the digital economy requires the government not only to increase investments in science, but also to qualitatively update the entire scientific system, including digital document management, platforms for knowledge and technology transfer, digital analytics and artificial intelligence in scientific research. Kazakhstan, as a state in an active phase of socio-economic transformation, sets itself the task of modernizing the scientific system through the introduction of digital technologies that meet international standards. In recent years, digital grant management platforms, online reporting systems, and individual elements of digital bibliometry have been emerging in the country, but the overall level of digital maturity of the scientific environment remains low. This creates obstacles to the integration of Kazakh science into the international scientific space and reduces the speed of innovative economic development. International experience, especially in South Korea, shows that the consistent digitalization of science can become a catalyst for economic growth, accelerate scientific research, strengthen technology transfer and increase the share of high-tech products in gross domestic product (GDP) [3]. In the context of global competition, Kazakhstan needs to rethink the strategic role of science in a digital society and identify key areas for its digital transformation, which requires not only institutional but also econometric foundations. The purpose of this article is to identify and quantify the impact of the digitalization of science on the competitiveness of

the economy of Kazakhstan, to determine the key parameters and conditions for the implementation of digital scientific transformation based on comparable international experience.

Materials and methods. The research is based on a comprehensive interdisciplinary approach to assessing the degree of digitalization of the scientific sphere and its impact on the competitiveness of the economy of the Republic of Kazakhstan in the context of the transformation of the global scientific and innovation agenda. Works on the digital transformation of science, knowledge economics, as well as models for assessing digital competitiveness (IMD, OECD) are used as a theoretical and methodological basis. The empirical database includes data from the Ministry of Science and Higher Education of the Republic of Kazakhstan, the Committee on Statistics, the National Center for Scientific and Technical Information, international sources (IMD, World Bank, OECD, ADB), as well as digital indicators from open scientific repositories [4,5]. Special attention is paid to materials on the scientific system of the Republic of Korea as a reference example of successful digitalization and effective integration of science into the digital economy.

Methodologically, the work is based on a combination of methods of comparative analysis, factor and index modeling, as well as elements of regression analysis. The central task was to build a sound quantitative model that would allow us to determine the degree of influence of the digitalization of scientific infrastructure on the digital competitiveness of the economy. For this purpose, the integrated index of digitalization of science (IDN) was proposed, which includes such parameters as the level of digitalization of scientific administration (including automation of grant processes, reporting and accounting of R&D results), the share of scientific publications in the public domain, the prevalence of digital skills among researchers, the introduction of advanced digital solutions (artificial intelligence, big data analysis, blockchain) in research activities, as well as the degree of integration of scientific organizations into international and national digital ecosystems. All indicators are normalized and aggregated into an integral indicator that allows for cross-country comparison and time analysis.

The constructed model is based on the premise that the digitalization of the scientific sphere has a multiplicative effect on such key components of digital competitiveness as innovation activity, technology transfer, efficiency of scientific expenditures and attraction of investments in the high-tech sector. To empirically verify the hypothesis put forward, a model of the dependence of the digital competitiveness index (according to the IMD methodology) on the integral index of digitalization of science, the share of R&D in GDP and the share of joint projects of science and business was formed. The calculations were based on panel data for 2018-2024. The model has been tested for statistical significance, stability, and interpretability. Standard regression analysis tools were used: coefficient determination, remainder analysis, multicollinearity and autocorrelation testing. In addition, expert assessments (the Delphi method) were used to verify qualitative parameters of digitalization, such as the digital competencies of researchers and the digital connectivity of scientific institutions.

The study also applied comparative logic: the Republic of Korea was chosen not only because of its leadership in the digitalization of science, but also because of the structural comparability of the scientific system with Kazakhstan in terms of the number of scientific institutions, the share of budget funding and the role of the state in the strategic management of science. This allows us to draw conclusions relevant to the Kazakh context. Information materials about the Korean scientific ecosystem are obtained from open sources (KISTI, NTIS, statistics Ministry of Science and ICT). The program documents of both countries were also analyzed, including the Digital Kazakhstan strategy, the state program of scientific and technological development of the Republic of Kazakhstan for 2023-2027, and the digital strategy of South Korea in the field of science and innovation. For quantitative comparison, such

indicators as the share of open access to scientific results (in Kazakhstan - 28%, in Korea - 82%), digitalization of scientific administration (40% and 95%, respectively), the share of researchers with advanced digital skills (in Kazakhstan - 22%, in Korea - 74%) were used. the number of R&D projects using AI and Big Data (in Kazakhstan - less than 10%, in Korea - over 35%).

To achieve the objectives of the study, a set of methods was used: comparative cross-country analysis, factorial and econometric analysis, as well as methods for constructing indexes. The research is based on statistical data from the Ministry of Science and Higher Education of the Republic of Kazakhstan, the World Bank, the IMD (Institute for Management Development), as well as analytical reports on science and digitalization of South Korea [6]. An integral indicator of the digitalization of science was developed, which includes the following components: the availability of digital scientific infrastructure, the degree of digitalization of management processes, the use of IT solutions in R&D, the level of digital literacy of researchers and the share of scientific publications in the public domain. Next, a linear regression model was built to analyze the impact of the digitalization of science on the digital competitiveness index of the economy:

$$C = \beta_0 + \beta_1 D + \beta_2 R + \beta_3 B + \varepsilon$$

where:

- C - Digital competitiveness index (IMD Digital Competitiveness);

- D - science digitalization index (0–1);

- R - R&D expenditures (% of GDP);

- B - share of joint science and business projects (% of all R&D);

- ε - an accidental mistake.

The data for 2024, presented in the table below, was used for quantitative assessment.

Table 1 - Comparison of indicators of the Republic of Kazakhstan and the Republic of Korea (2024)

Indicator	Republic of Kazakhstan	Republic of Korea
Science Digitalization Index (DDD)	0,45	0,78
RD expenses (% of GDP) (RRR)	0,80	4,90
The share of science-business projects (BBB)	12 %	35 %
Digital Competitiveness Index (C)	34th place	8th place
Note. Compiled based on the source [7]		

Results and discussion. The econometric and comparative analysis revealed a number of important relationships, confirming that the level of digitalization of the scientific sphere directly affects key macroeconomic parameters, in particular the index of digital competitiveness, innovation activity and R&D productivity. The main regression model showed that the coefficient for the variable characterizing the digitalization of science (DDD) is 12.1, which indicates a high sensitivity of competitiveness to even minor changes in the level of digitalization. This means that the strategic expansion of digital infrastructure and tools in the scientific field can ensure the rapid development of not only the scientific sector itself, but also the economy as a whole due to multiplier effects. Additionally, calculations show that with the simultaneous improvement of all three indicators - the level of digitalization, the volume of R&D and the share of joint projects with businesses - it is possible to achieve an increase in the country' s digital competitiveness index by 4-6 points over 3-5 years. This is significant given the current international competition in the field of science and

technology, where even one rating point can affect investment flows and international cooperation.

In addition to the basic model, an assessment was made of the differences in the implementation of digital scientific initiatives between Kazakhstan and the Republic of Korea. The results are shown in the table:

Table 2 - Comparison of key areas of digitalization of science: Kazakhstan and the Republic of Korea in 2024

The direction of digitalization	Republic of Kazakhstan	Republic of Korea
Unified Digital Science Platform	Missing, using disparate ICS	KISTI, NTIS – integrated platforms
Open access to data and publications	Partial, non-integrated	Full, through the state platform
Automating grant allocation	Partially implemented (Science Fund)	Fully automated via KIAT
Integration of science and business	Low, 12% of projects are joint	High, more 35 %
The use of AI and Big Data in science	Local pilot projects	At the level of national scientific programs
Digital certification of results	Practically absent	Mandatory for all RD
Digital skills of scientific staff	Limited, fragmentary training	Integrated into PhD programs and Master's degree programs
Standards of open science	They are not legally fixed	Implemented and mandatory since 2020
Note – Developed by the authors		

As can be seen from the table, Kazakhstan' s lag is not so much due to the lack of basic digital solutions, but rather to the lack of a systemic strategy and coordination between participants in the scientific ecosystem. South Korea, on the contrary, was able to build a vertically integrated model of digital science, where each link - from universities to government agencies and businesses – operates within the framework of a common architecture [8]. In Kazakhstan, such elements exist in isolation and do not produce a synergistic effect. However, it is important to note that the potential for digitalization in the country remains high: the presence of technical universities, digital hubs, government support for the IT sector and the strategies «Digital Kazakhstan» and «Science, Technology and Innovation - 2023-2027» creates the necessary conditions for the transition to a digital model of science [9].

Thus, the main conclusions from the analysis are as follows: (1) the digitalization of science has a quantifiably significant impact on the economy and its competitiveness; (2) Kazakhstan' s current position in the ratings and integrated digitalization indices remains below average, but demonstrates growth potential.; (3) The gap with developed countries is due to institutional and organizational barriers, not technical impossibility; (4) with the implementation of a holistic policy of digitalization of science, a short-term increase in the country' s international position and an increase in the effectiveness of science as an industry are possible. The expected effect of improving digitalization is expressed not only in increasing ratings, but also in economic benefits: according to the calculations of the model, even with a conditional increase

in the digitalization index of science by 0.2 (for example, from 0.45 to 0.65), an increase in innovation productivity is expected by 15-18%, a reduction in transaction costs by 20% and an increase in technology transfer by 25-30%. In the long term, this translates into an increase in the share of knowledge-intensive industries in GDP, the formation of sustainable competitive advantages and a reduction in dependence on the raw materials sector.

Thus, the digitalization of science in Kazakhstan is not only a matter of modernizing the research environment, but also a strategic vector of transformation of the entire economy. It is necessary to accelerate the implementation of digital solutions, synchronize policies in science, education and innovation, as well as enhance international scientific cooperation through digital tools.

Conclusion. At the present stage, the digitalization of science in the Republic of Kazakhstan is becoming an integral part of the formation of a competitive economy focused on innovative development and integration into the global scientific and technological space. The results of the study confirm that the level of digitalization of the scientific sphere has a significant impact on macroeconomic indicators, including the country' s digital competitiveness index, R&D productivity, innovation activity and investment attractiveness of high-tech industries [10]. However, the current level of digital maturity of Kazakh science is assessed as insufficient: there is no single digital platform covering all levels of scientific activity, there is a low share of digital services in the science management system, digital analytics and automation of scientific knowledge assessment and transfer processes are poorly developed. Additionally, structural problems have been identified, such as weak integration of science and business, limited access to international digital databases, and the lack of digital mechanisms for certification and verification of research results [11].

These barriers reduce the effectiveness of public investment in science and hinder the country' s innovation potential. To overcome these problems, it is necessary to implement a comprehensive strategy for the digitalization of science, including legislative support for digital transformation, the development of a unified scientific digital ecosystem, the introduction of open science standards, digital identifiers, and ensuring the cybersecurity of scientific data. A key focus should be the stimulation of intersectoral cooperation – between science, business and government - through digital platforms for joint research and development, the use of blockchain and AI technologies to manage scientific cycles and the introduction of digital KPIs to assess scientific effectiveness [12]. In addition, it is necessary to develop digital competencies among all participants in the scientific process: researchers, teachers, managers and experts, through targeted educational programs and digital acceleration. Only in the case of a systematic approach, the digitalization of science can become a powerful catalyst for the transition to a knowledge economy and ensure Kazakhstan' s sustainable competitive advantage in the context of the fourth industrial revolution and global technological competition.

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